Chapter 5
Academic Research and Development

Highlights

Financial Resources for Academic R&D

- ♦ **In 2000, U.S. academic institutions spent an estimated $30 billion (in current dollars) on research and development (R&D).** The Federal Government provided $17.5 billion, academic institutions $6.0 billion, state and local governments $2.2 billion, industry $2.3 billion, and other sources $2.2 billion.
- ♦ **Over the past half century (between 1953 and 2000), average annual growth in R&D has been stronger for the academic sector than for any other R&D-performing sector.** During this period, academic R&D rose from 0.07 to 0.30 percent of the gross domestic product, more than a fourfold increase. Industrially performed R&D has grown more rapidly in recent years than R&D performed in any other sector.
- ♦ **The academic sector, which performs 43 percent of basic research, continues to be the largest performer of basic research in the United States.** Academic R&D activities have been highly concentrated at the basic research end of the R&D spectrum since the late 1950s. In 2000, an estimated 69 percent of academic R&D expenditures went for basic research, 24 percent for applied research, and 7 percent for development.
- ♦ **The Federal Government continues to provide the majority of funds for academic R&D, although its share has been declining steadily since 1966.** The Federal Government provided an estimated 58 percent of the funding for R&D performed in academic institutions in 2000, down from its peak of 73 percent in the mid-1960s.
- ♦ **After the Federal Government, academic institutions performing R&D provided the second largest share of academic R&D support.** Except for a brief downturn in the first half of the 1990s, the institutional share of academic R&D support has been increasing steadily since the early 1960s, reaching an estimated 20 percent in 2000. Some of the funds directed to research activities by institutions come from Federal, state, or local government sources but are classified as institutional funds because they are not restricted to research and the universities decide how to use them.
- ♦ **Industrial R&D support to academic institutions has grown more rapidly (albeit from a small base) than support from all other sources during the past quarter century.** Industry's share was an estimated 7.7 percent in 2000, its highest level since the 1950s. However, industrial support still accounts for one of the smallest shares of academic R&D funding.
- ♦ **Three agencies are responsible for more than four-fifths of Federal obligations for academic R&D: the National Institutes of Health (NIH) for 60 percent, the National Science Foundation (NSF) for 15 percent, and the Department of Defense for 9 percent.** Federal agencies emphasize different science and engineering (S&E) fields in their funding of academic research, with some, such as NIH, concentrating their funding in one field and others, such as NSF, having more diversified funding patterns.
- ♦ **After increasing steadily between the early 1970s and early 1990s, the number of universities and colleges receiving Federal R&D support began to decline after 1994.** Almost the entire increase during that period, and the recent decrease, occurred among institutions other than those classified by the Carnegie Foundation for the Advancement of Teaching as research and doctorate-granting institutions. Of these institutions, 559 received Federal R&D support in 1999 compared with 676 in 1994, 461 in 1980, and 341 in 1971.
- ♦ **The R&D emphasis of the academic sector, as measured by its S&E field shares, changed between 1973 and 1999, with absolute shares increasing for life sciences, engineering, and computer sciences and declining for social sciences, psychology, environmental (earth, atmospheric, and ocean) sciences, and physical sciences.** In 1999, life sciences accounted for 57 percent of total academic R&D expenditures, 56 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures.
- ♦ **The distribution of Federal and non-Federal funding of academic R&D varies by field.** In 1999, the Federal Government supported more than three-quarters of academic R&D expenditures in both physics and atmospheric sciences but one-third or less of the R&D in economics, political science, and agricultural sciences.
- ♦ **Total academic space for S&E research increased by almost 35 percent between 1988 and 1999, up from about 112 million to 151 million net assignable square feet.** When completed, construction projects initiated between 1986 and 1999 are expected to produce more than 72 million square feet of new research space, which will either replace obsolete or inadequate space or be added to existing space.
- ♦ **R&D equipment intensity—the percentage of total annual R&D expenditures from current funds devoted to research equipment—has declined dramatically during the past 15 years.** After reaching a high of 7 percent in 1986, R&D equipment intensity declined to 5 percent in 1999.

Doctoral Scientists and Engineers in Academia

- **An estimated 28 percent of doctoral scientists and engineers at U.S. universities and colleges in 1999 were foreign born.** Computer sciences and engineering had the highest percentages (37 and 35 percent, respectively); followed by mathematics (28 percent); physical, life, and social sciences (from 23 to 19 percent); and psychology (8 percent). Many of these scientists and engineers had obtained their doctorates from U.S. institutions. These estimates are conservative and do not reflect the strong rise in immigration during the 1990s.
- **University hiring of young faculty is picking up, but full-time faculty appointments are less available than ever.** Those entering academia with recently earned doctorates are more likely to receive postdoctoral (43 percent) than faculty positions (39 percent). Only half of those with a doctorate earned four to seven years earlier are in tenure track positions, well below the experience of previous decades.
- **Among new hires, the percentage of white males has been cut in half, from 80 percent in 1973 to 40 percent in 1999,** reflecting a declining propensity to earn a S&E doctorate and the relative attractiveness of nonacademic employment. Growth occurred in the hiring of women and young doctorate-holders from minority backgrounds.
- **An academic researcher pool outside the regular faculty ranks has grown over the years.** The faculty share of the academic workforce has declined, as more research activity is being carried out by postdoctorates and others in full-time nonfaculty positions. This change toward nonfaculty research effort was pronounced in the 1990s. A long-term upward trend shows those with primary research activity increasing relative to total employment.
- **Graduate students play a key role in U.S. academic S&E research, and research assistantships were the primary means of support for about one-quarter of them.** The number of research assistants has risen faster than overall graduate enrollment. A shift is evident away from the physical and into the life sciences, reflecting changes in the field distribution of academic research funds.
- **The percentage of academic researchers with Federal support for their work was lower in 1999 than in the late 1980s.** Exceptions were engineering; computer sciences; and earth, atmospheric, and ocean sciences. Full-time faculty were less frequently supported than other full-time employees, especially postdoctorates, 80 percent of whom received Federal funds. Young Ph.D.-holders in full-time faculty positions reported sharply lower rates of Federal support than their counterparts in other positions.
- **In the view of academic researchers, no large shift has taken place during the 1990s in the nature of academic R&D.** Of those with research as their primary work activity, a modestly larger percentage reported applied and development work in 1999 than in 1993. Among all academic researchers, no such effect was evident.

Outputs of Scientific and Engineering Research: Articles and Patents

- **In 1999, authors from around the world published approximately 530,000 articles in a set of refereed journals included in the Science Citation Index since 1985.** This represented an average increase of 1 percent per annum from the prior decade, with very disparate growth patterns by region. Authors from Western Europe, Asia, and Latin America achieved strong growth in papers; authors from the United States, Eastern Europe, and Sub-Saharan Africa showed a decline of articles in absolute terms.
- **The number of U.S.-authored papers (approximately 164,000 articles in 1999) appear to have fallen from the level in the early 1990s.** This phenomenon is not exclusive to the United States; output fell in the United Kingdom, Canada, and the Netherlands during the latter half of the 1990s. The trend in the United States affected all fields of science, except earth and space science, and most sectors. Although the U.S. share of world output has been in a long-term decline due to strong growth in other countries, the absolute U.S. output volume had grown consistently over the prior three decades.
- **The U.S. portfolio of scientific papers is broad and diverse, although it is dominated by life sciences, particularly biomedical research and clinical medicine.** Social and behavioral sciences also are an important component in the U.S. portfolio. As a region, Western Europe has a similar life-science dominated portfolio, but for major European nations the physical sciences shares are larger than in the U.S. A portfolio consisting of physical sciences and engineering is much more prominent for countries in Eastern Europe, Asia, and Latin America.
- **Scientific collaboration between institutions has increased significantly over the past two decades as a result of IT, the growing complexity and scale of scientific research, and economic and political factors.** In the United States, more than half of all articles in 1999 had authors from multiple institutions, primarily due to a significant rise in international collaboration. By 1999, 1 article in 5 had one non-U.S. author compared with 1 article in 10 in the 1980s.

- **The U.S. has the largest share of internationally authored papers, although this share has declined as other countries have increased and expanded their ties with other countries.** U.S. authors partnered with authors from 160 countries in 1999, and those countries ranged from mature scientific producers of OECD to developing countries. Countries with authors with high levels of collaboration included Western European countries, Japan, Russia, and the newly industrialized economies in Asia. Collaboration also increased in other regions, both intraregionally and with other regions, especially the United States, Western Europe, and Asia.

- **In the United States, collaboration between institutions is extensive, accounting for at least 77 percent of multiple-authored papers by all institutions except academia.** Academia is the center of cross-sector collaboration and plays a key role in the life sciences and chemistry fields. Other distinct partnerships include the private sector in life sciences, chemistry, earth and space sciences, and the Federal Government in earth and space science, and physics.

- **The pattern of research cited by scientific papers is underscored by the prominence of U.S. and Western Europe research cited adjusted for their world share of literature.** The United States is the most highly cited on a regional basis and is prominent in the fields of clinical medicine, biomedical research, chemistry, earth and space science, and social and behavioral sciences. Several Western European countries, notably Switzerland, the Nordic countries, Denmark, and the Netherlands, also are highly cited based on their world share of literature.

- **Developing and emerging countries are cited with less frequency than mature science producers are, but several countries are highly cited in specific fields.** In addition, the citation of Latin American literature, adjusted for its world share of literature, has risen markedly. The United States and Western Europe are the most prominently cited by developing regions, but Latin America and sub-Saharan Africa cite each other's literature at a fairly high degree.

- **Academic patenting has continued to increase and now accounts for 5 percent of all U.S.-owned patents.** Academic patenting is more heavily concentrated in particular application areas than U.S. patenting in general, with especially heavy weight on life sciences applications.

- **Universities are increasingly taking equity positions in spinoff companies as a way of capitalizing on their intellectual property.** The number of equity licenses and options executed grew from 99 in 1995 to 272 in 1998 and 243 in 1999. The total number of new licenses and options reached almost 3,300. Gross royalties in 1999 were $641 million, more than double the 1995 amount.

- **The increase in citations of U.S. patents to research suggests the growing importance of science in practical application of technology.** Over the past two decades, the research citations of U.S. patents rose more than 10-fold, largely because of increases in the life sciences. Citations to most other fields also increased, but at a much lower rate.

- **U.S. literature is the most highly cited (on the basis of relative U.S. share of literature) in U.S. patents by both domestic and foreign inventors.** Asian literature in engineering and technology and physics also is prominently cited by Western European and U.S. inventors, respectively.

Introduction

Chapter Background

A strong national consensus supports the public funding of academic research, and although the Federal Government plays a diminishing role, it still provides close to 60 percent of the financial resources. More than half of academic research and development (R&D) funds go to the life sciences, and this share increased during the past quarter century, raising concern about whether the distribution of funds is appropriately balanced. The number of academic institutions receiving Federal support for R&D activities increased dramatically during the past several decades, expanding the base of the academic R&D enterprise. Recently, however, this number began to decline. The Federal Government plays a minor role in providing direct support to universities and colleges for construction of their research facilities. Nevertheless, the amount of academic science and engineering (S&E) research space grew continuously over the past decade. In contrast, the Federal Government accounted for almost 60 percent of direct expenditures of current funds for academic research equipment, but the percentage of total annual R&D expenditures devoted to such equipment declined noticeably during the past decade. Doctoral S&E faculty in universities and colleges play a critical role in ensuring an adequate, diverse, and well-trained supply of S&E personnel for all sectors of the economy. Until recently, positive outcomes and impacts of R&D were taken for granted; however, the system has begun to face demands that it devise means and measures to account for specific Federal R&D investments.

This chapter addresses key issues of the academic R&D enterprise, such as the importance of a Federal role in supporting academic research; the appropriate balance of funding across S&E disciplines; the breadth and strength of the academic base of the nation's S&E and R&D enterprise; the adequacy of research facilities and instrumentation at universities and colleges; the role of doctoral S&E faculty, including both their teaching and their research responsibilities; and accountability requirements, including measuring outputs and larger social outcomes.

Chapter Organization

The first section of this chapter discusses trends in the financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. Because the Federal Government has been the primary source of support for academic R&D for more than half a century, the importance of selected agencies in supporting individual fields is explored in detail. This section also presents data on changes in the number of academic institutions that receive Federal R&D support and then examines the status of two key elements of university research activities: facilities and instrumentation.

The next section discusses trends in the employment of academic doctoral scientists and engineers and examines their activities and demographic characteristics. The discussion of employment trends focuses on full-time faculty, postdoctorates, graduate students, and other positions. Differences between the nation's largest research universities and other academic institutions are considered, as are shifts in the faculty age structure. The involvement of women and underrepresented minorities, including Asians/Pacific Islanders, is also examined. Attention is given to participation in research by academic doctoral scientists and engineers, the relative balance between teaching and research, and Federal support for research. Selected demographic characteristics of recent doctorate-holders entering academic employment are reviewed.

The chapter concludes with an assessment of two research outputs: scientific and technical articles in a set of journals covered by the Science Citation Index (SCI) and the Social Science Citation Index (SSCI) and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in the preceding section of this chapter and in chapter 2). This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature on patent applications). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D

Academic R&D is a significant part of the national R&D enterprise.[1] Enabling U.S. academic researchers to carry out world-class research requires adequate financial support as well as excellent research facilities and high-quality research equipment. Consequently, assessing how well the academic R&D sector is doing, the challenges it faces, and how it is responding to those challenges requires data and information on a number of important issues relating to the financing of academic R&D, including:

- the level and stability of overall funding,
- the sources of funding and changes in their relative importance,
- the distribution of funding among the different R&D activities (basic research, applied research, and development),
- the balance of funding among S&E fields and subfields (or fine fields),
- the distribution of funding among various types of academic R&D performers and the extent of their participation,

[1] Federally funded research and development centers (FFRDCs) associated with universities are tallied separately and are examined in greater detail in chapter 4. FFRDCs and other national laboratories (including Federal intramural laboratories) also play an important role in academic research and education, providing research opportunities for both students and faculty at academic institutions.

- the changing role of the Federal Government as a supporter of academic R&D and the particular roles of the major Federal agencies funding this sector, and
- the state of the physical infrastructure (research facilities and equipment) that is a necessary input to the sector's success.

Individually and in combination, these issues influence the evolution of the academic R&D enterprise and therefore are the focus of this section. For a discussion of the nature of the data used in this section, see the sidebar, "Data Sources for Financial Resources for Academic R&D."

Academic R&D Within the National R&D Enterprise

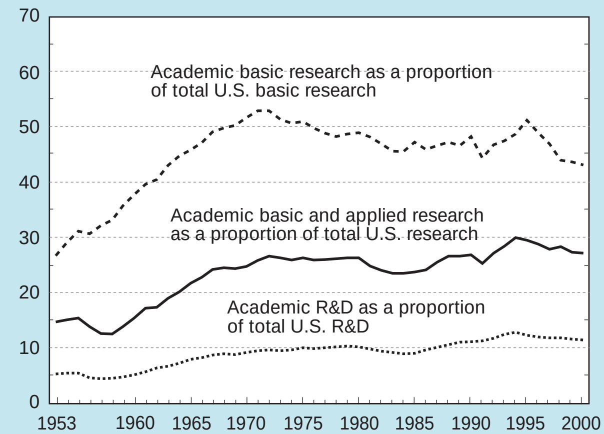
The continuing importance of academia to the nation's overall R&D effort is well accepted today.[2] This is especially true for its contribution to the generation of new knowledge through basic research. During the 1990s, academia accounted for slightly less than half of the basic research performed in the United States.

In 2000, U.S. academic institutions spent an estimated $30 billion, or $28 billion in constant 1996 dollars, on R&D.[3] This was the 26th consecutive year in which constant-dollar spending increased from the previous year. Academia's role as an R&D performer has increased steadily during the past half century, rising from about 5 percent of all R&D performed in the United States in 1953 to almost 11 percent in 2000. (See figure 5-1.) However, since 1994, the sector's performance share has dipped slightly from its high of almost 13 percent. The decline in the academic share is the result of rapid growth in industrial R&D performance. See the section "Growth" below. For a comparison with other industrial countries, see the sidebar, "Comparisons of International Academic R&D Spending."

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity.[4] For academic R&D expenditures in 2000, an estimated 93 percent went for research (69 percent for basic and 24 percent for applied) and 7 percent for development. (See figure 5-2.) From the perspective of national research, as opposed to national R&D, academic institutions accounted for an estimated 27 percent of the U.S. total in 2000. The academic share of research almost doubled, from about 14 percent of the U.S. total in the 1950s to around 26 percent in the first half of the 1970s. (See figure 5-1.) It has since fluctuated between 23 and 30 percent. In terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 43 per-

Figure 5-1.
Academic R&D, basic and applied research, and basic research as a proportion of U.S. totals: 1953–2000

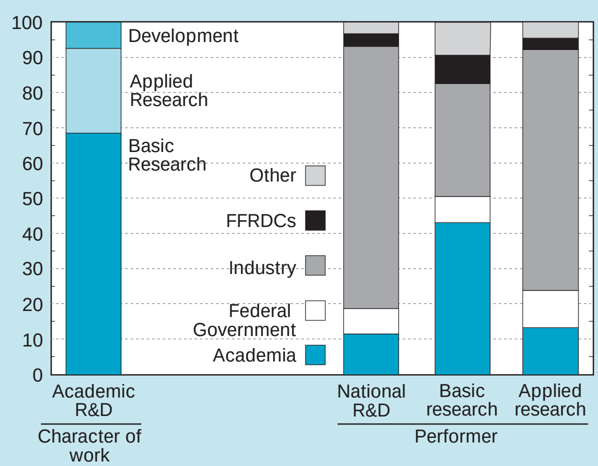


NOTE: Data for 1999 and 2000 are preliminary.

See appendix tables 4-3, 4-7, and 4-11.

Science & Engineering Indicators – 2002

Figure 5-2.
Academic R&D expenditures, by character of work, and national R&D expenditures, by performer and character of work: 2000



FFRDC = Federally Funded Research and Development Center

NOTE: Data are preliminary.

See appendix tables 4-3, 4-7, 4-11 and 5-1.

Science & Engineering Indicators – 2002

[2] For more detailed information on national R&D expenditures, see "R&D Performance in the United States " in chapter 4.

[3] For this discussion, an academic institution is generally defined as an institution that has a doctoral program in science or engineering, is a historically black college or university that expends any amount of separately budgeted R&D in S&E, or is some other institution that spends at least $150,000 for separately budgeted R&D in S&E.

[4] Despite this delineation, the term "R&D" (rather than just "research") is primarily used throughout this discussion because data collected on academic R&D often do not differentiate between research and development. Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in NSF resource surveys and a fuller discussion of these concepts, see chapter 4.

Data Sources for Financial Resources for Academic R&D

The data used to describe financial resources for academic R&D are derived from several National Science Foundation (NSF) surveys and one National Center for Education Statistics (NCES) survey. These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. NSF's four main surveys involving academic R&D are as follows:

1. the Survey of Federal Funds for Research and Development,
2. the Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions,
3. the Survey of Research and Development Expenditures at Universities and Colleges, and
4. the Survey of Scientific and Engineering Research Facilities.

The NCES survey used is the Integrated Postsecondary Education Data System (IPEDS) Finance Survey. The first two NSF surveys collect data from Federal agencies, whereas the last two NSF surveys and the NCES survey collect data directly from universities and colleges.*

Data presented in the context section, "Academic R&D Within the National Enterprise," are derived from *National Patterns of R&D Resources* (National Science Foundation (NSF) 2000), a report that aggregates NSF survey data on the various sectors of the U.S. economy so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 1999 and 2000 are preliminary. Data in subsequent sections are reported on an academic or fiscal-year basis and therefore differ from those reported in this section. Data on major funding sources, funding by institution type, distribution of R&D funds across academic institutions, and expenditures by field and funding source are from the Survey of Research and Development Expenditures at Universities and Colleges. For various methodological reasons, parallel data by field from the NSF Survey of Federal Funds for Research and Development do not necessarily match these numbers.

The data in the section "Emphasis on Research at Universities and Colleges" are drawn from the NCES IPEDS finance survey. Although the definition of research used in this survey is similar to that used in NSF surveys, the data collected include fields other than S&E and do not include many of the indirect costs associated with research; thus, they are not comparable with other data presented in this chapter. The IPEDS Finance Survey reports indirect costs as part of lump sums in other separate expenditure categories, such as academic support, institutional support, and operation and maintenance of plant, rather than distributing these costs to the research, instruction, and public service functions. Data for 1996 were the most recent available at the time this report was prepared. (For more information about indirect costs, see the sidebar, "Recent Developments on the Indirect Cost Front," later in this chapter.)

The data in the "Federal Support of Academic R&D" section come primarily from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations from about 30 Federal agencies. Data for fiscal year (FY) 2000 and FY 2001 are preliminary estimates. The amounts reported for FY 2000 reflect congressional appropriation action as of the third quarter of FY 2000, the period in which the last survey was conducted. Data for FY 2001 represent administration budget proposals that had not been acted on. Data on Federal obligations by S&E field are available only for FY 1999, as they are not estimated and refer only to research (basic and applied) rather than to research plus development.

The data in the section "Spreading Institutional Base of Federally Funded Academic R&D" are drawn from NSF's Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions. This survey collects data on Federal R&D obligations to individual U.S. universities and colleges from the approximately 18 Federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Survey of Research and Development Expenditures at Universities and Colleges.

Data on facilities are taken from the Survey of Scientific and Engineering Research Facilities. Data on research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Although terms are defined specifically in each survey, in general, facilities expenditures are classified as "capital" funds, are fixed items such as buildings, often cost millions of dollars, and are not included within R&D expenditures as reported here. Equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Expenditures on research equipment are limited to current funds and do not include expenditures for instructional equipment. Current funds, as opposed to capital funds, are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

* For descriptions of the methodologies of the NSF surveys, see NSF 1995a and 1995b and the Division of Science Resources Statistics website: <http://www.nsf.gov/sbe/srs/stats.htm>. Information about the NCES survey is available at the NCES website: <http://www.ed.gov/NCES>.

cent of the national total. Between 1953 and 1972, the academic sector's basic research performance grew steadily, increasing from about one-quarter to slightly more than one-half of the national total. It has since fluctuated at between 43 and 51 percent of the national total.

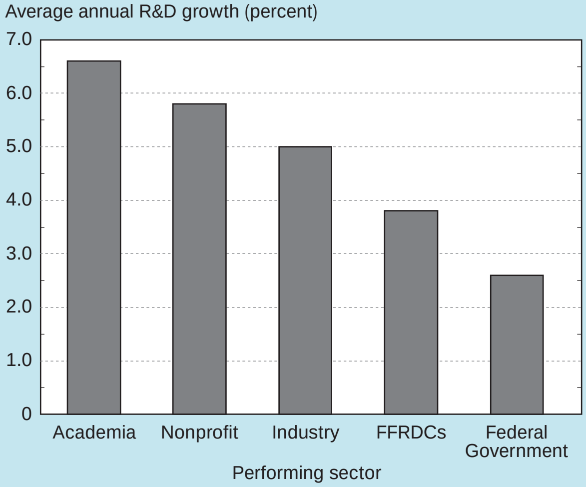
Growth

Over the course of the past half century (1953 to 2000), the average annual R&D growth rate (in constant 1996 dollars) of the academic sector has been higher than that of any other R&D-performing sector at 6.6 percent compared with about 5.8 percent for other nonprofit entities, 5.0 percent for industry, 3.8 for federally funded research and development centers (FFRDCs), and 2.6 percent for the Federal Government. (See figure 5-3 and appendix table 4-4 for time series data by R&D performing sector.) However, during the second half of the 1990s, average annual R&D growth within industry (an estimated 6.9 percent) was higher than at academic institutions (an estimated 4.1 percent). As a proportion of gross domestic product (GDP), academic R&D rose from 0.07 to 0.30 percent between 1953 and 2000, more than a fourfold increase. (See appendix table 4-1 for GDP time series.)

Major Funding Sources

The academic sector relies on a variety of funding sources for support of its R&D activities. Although the Federal Government continues to provide the majority of funds, its share has declined steadily since reaching a peak of slightly more than 73 percent in 1966. In 2000, the Federal Government accounted for an estimated 58 percent of the funding for R&D performed in academic institutions, its lowest share since the late 1950s. (See figure 5-4.) The Federal sector primarily supports basic research; 74 percent of its 2000 funding went to basic research versus 26 percent to applied R&D. (See appendix table 5-1.) Non-Federal sources also are used predominantly for basic research; 62 percent of its 2000 funding went to basic research versus 38 percent to applied R&D).

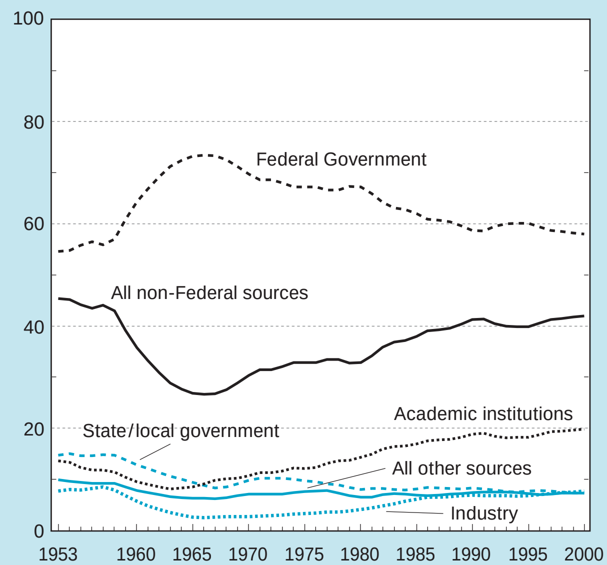
Figure 5-3.
Average annual R&D growth, by performing sector: 1953–2000



FFRDC = Federally Funded Research and Development Center

See appendix table 4-4. *Science & Engineering Indicators – 2002*

Figure 5-4.
Sources of academic R&D funding: 1953–2000



NOTE: Data for 1999 and 2000 are preliminary.

See appendix table 5-2. *Science & Engineering Indicators – 2002*

Federal support of academic R&D is discussed in detail later in this section; the following list summarizes the contributions of other sectors to academic R&D:[5]

- ♦ **Institutional funds.** In 2000, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for an estimated 20 percent, the highest level during the past half century. Institutional funds encompass three categories: separately budgeted funds from unrestricted sources that an academic institution spends on R&D, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on Federal and other grants. For more detailed discussions of both indirect costs and the composition of institutional funds, see the sidebars "The Composition of Institutional Academic R&D Funds" and "Recent Developments on the Indirect Cost Front."

The share of support represented by institutional funds has been increasing steadily since the early 1960s, except for a brief downturn in the early 1990s. Institutional R&D funds

[5] The academic R&D funding reported here includes only separately budgeted R&D and institutions' estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing. It does not include departmental research and thus will exclude funds, notably for faculty salaries, in cases where research activities are not separately budgeted.

Comparisons of International Academic R&D Spending

Countries differ in the proportion of their research and development that is performed at institutions of higher education. Among the G-7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) R&D performed in the academic sector, as a proportion of total R&D performance, varied between 12 percent in the United States and 25 percent in Italy. In Russia, only 5 percent of R&D was performed in academic institutions. (See text table 5-1.)

A number of factors may account for the differences in the role academia plays in the performance of R&D from country to country. The distribution of a country's R&D expenditures among basic research, applied research, and development affects the share performed by higher education. Because the academic sector primarily carries out research (generally basic) rather than development activities, countries in which development activities take greater prominence rely less on the academic sector for overall R&D performance. The importance of other sectors in R&D performance also affects the academic sector's share. Among the G-7 countries, the United States has the highest share of R&D performed by industry.* Institutional and cultural factors such as the role and extent of independent research institutions, national laboratories, and government-funded or -operated research centers, probably also affect the academic sector's share.

Finally, different accounting conventions among countries may account for some of the differences reported. The national totals for academic R&D for Europe, Canada, and Japan include the research components of general university funds (GUF) provided as block grants to the academic sector by all levels of government. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental research activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at U.S. public universities. Universities generally do not maintain data on departmental research, which is considered an integral part of instruction programs. U.S. totals thus may be underestimated relative to the academic R&D efforts reported for other countries.

Text table 5-1.
Academic R&D as percentage of total R&D performance: 1998 or 1999

United States	12
Canada	24
France	18
Germany	17
Italy	25
Japan	15
Russia	5
United Kingdom	20

See appendix table 4-42.

Science & Engineering Indicators – 2002

*See "International R&D by Performer, Source, and Character of Work" in chapter 4 for more detailed information, including data on the sources of funding for academic R&D in different countries.

may be derived from (1) general-purpose state or local government appropriations (particularly for public institutions) or Federal appropriations; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) unrestricted gifts. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. See "Patents Awarded to U.S. Universities" later in this chapter for a discussion of patent and licensing income.

- **State and local government funds.** State and local governments provided an estimated 7 percent of academic R&D funding in 2000. They played a larger role during the early 1950s, when they provided about 15 percent of the funding. Since 1980, the state and local share of academic R&D funding has fluctuated between 7 and 8 percent. This share, however, only reflects funds directly targeted to academic R&D activities by the state and local governments. It does not include general-purpose state or local government appropriations that academic institutions designate and use for separately budgeted research or to cover unreimbursed indirect costs.[6] Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

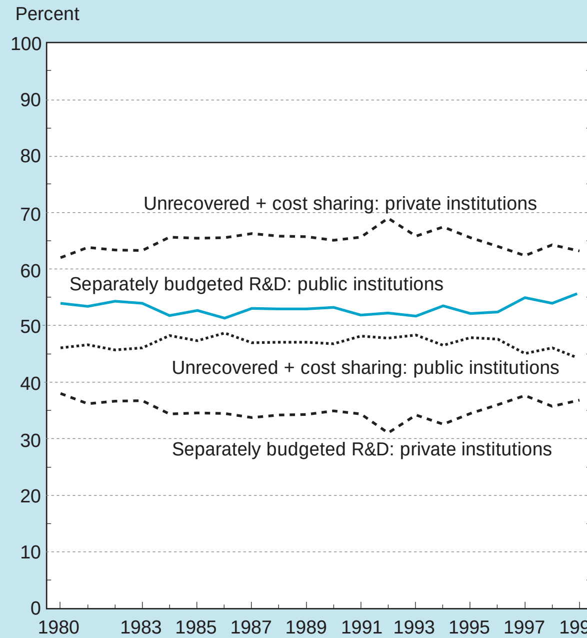
- **Industry funds.** In 2000, industry provided an estimated 8 percent of academic R&D funding. The funds provided for academic R&D by the industrial sector grew faster than funding from any other source during the past three decades, although industrial support still accounts for one of the smallest shares of funding. Industrial funding of academic R&D has never been a major component of industry-funded R&D. During the 1950s, industry's share was actually larger than it is currently, peaking at 8.5 percent in 1957. In 1994, industry's contribution to academic R&D represented 1.5 percent of its total support of R&D compared with 1.4 percent in 1990, 0.9 percent in 1980, 0.6 percent in 1970, and 1.1 percent in 1958. Since 1994, the share

[6] This follows a standard of reporting that assigns funds to the entity that determines how they are to be used rather than to the one that necessarily disburses the funds.

The Composition of Institutional Academic R&D Funds

During the past three decades, institutional funds for academic R&D grew faster than funds from any other sources except industry and faster than any other source during the past five years. (See appendix table 5-2.) In 2000, academic institutions are estimated to have committed a substantial amount of their own resources to R&D: roughly $6 billion, or 20 percent of total academic R&D. In 1999, the share of institutional support for academic R&D at public institutions (24 percent) was greater than at private institutions (9 percent). (See appendix table 5-3.) One possible reason for this large difference in relative support is that public universities and colleges' own funds may include considerable state and local funds not specifically designated for R&D but used for that purpose by the institutions. Throughout the 1980s and 1990s, institutional R&D funds were divided roughly equally between two components: separately budgeted institutional R&D funds and mandatory and voluntary cost sharing plus unreimbursed indirect costs associated with R&D projects financed by external organizations. Institutional funds at public and private universities and colleges differ not only in their importance to the institution but also in their composition. From 60 to 70 percent of private institutions' own funds were designated for unreimbursed indirect costs plus cost sharing compared with 44 to 50 percent of public institutions' own funds. (See figure 5-5.) For information about recent changes in indirect cost policy, see the sidebar, "Recent Developments on the Indirect Cost Front."

Figure 5-5.
Components of institutional R&D expenditures for public and private academic institutions: 1980–99



SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Academic Research and Development Expenditures, special tabulations.

Science & Engineering Indicators – 2002

Recent Developments on the Indirect Cost Front

About three-quarters of the Federal investment in academic R&D supports the direct costs of conducting research, that is, those costs that can be directly attributed to a research project. The remainder of the investment reimburses indirect costs. These are general expenses that cannot be associated with specific research projects but pay for things that are used collectively by many research projects at an academic institution. Two major components of indirect costs exist: (1) the construction, maintenance, and operation of facilities used for research and (2) the support of administrative expenses such as financial management, institutional review boards, and environment, health, and safety management. The Office of Management and Budget (OMB) Circular A-21, the document governing indirect cost reimbursement policies, documentation, and accounting practices, refers to these costs as "facility and administrative" (F&A) costs (U.S. Office of Management and Budget (U.S. OMB) 2000). F&A rates are established through negotiations between the Federal Government and individual institutions and are then generally used to determine the F&A reimbursement.

In 1998, Congress, through the National Science Foundation Authorization Act (Public Law 105-207), directed the Office of Science and Technology Policy (OSTP) to address six issues related to the ways universities and colleges recover indirect costs incurred in performing research under Federal grants and contracts:

1. comparison of indirect cost rates across sectors,
2. distribution of rates by spending category,
3. the impact of changes in OMB Circular A-21,
4. the impact of Federal and state law on rates,
5. options to reduce or control the rate of growth of reimbursement rates, and
6. options for creating an indirect cost database.

In July 2000, OSTP produced a report addressing these issues (U.S. Office of Science and Technology Policy (U.S.

OSTP) 2000). In conducting its analyses, OSTP used input from a report that it commissioned from RAND (Goldman et al. 2000), data provided by the Council on Governmental Relations, discussions and data provided by a small group of public and private research universities, discussions with OMB and other Federal agencies, and other unpublished reports. In its analysis of the six major issues raised by Congress, OSTP concluded the following:

1. **Comparison of F&A rates across sectors.** Rates at universities and colleges appear to be slightly lower than those at other types of research institutions, such as Federal laboratories and industrial facilities.

2. **Distribution of F&A rates by spending category.** Negotiated F&A rates have remained stable at approximately 50 percent for at least a decade. The average rates for administration have declined somewhat, although rates for facilities have increased. The decline in the administrative rate can be attributed to the imposition of the administrative cap in 1991; however, the F&A rate often is not an accurate reflection of an institution's actual recovery. (See item 4 below.)

3. **Impact of changes in OMB Circular A-21.** During the 1990s, OMB implemented a number of changes in Circular A-21 to limit the payment of certain costs, to provide clarification for consistent treatment of other costs, and to simplify some administrative procedures. During 1993, the first full year of the 26 percent administrative cap, negotiated administrative rates fell by about 2 percent and have since remained constant. Depreciation/use allowance rates for buildings and equipment have increased gradually from 6 percent in 1988 to approximately 9 percent in 1999, although some of the increase has been offset by reductions in operations and maintenance rates.

4. **Impact of Federal and state laws on F&A rates.** Some Federal statutes and agency policies may limit the amount a university can recover. Moreover, state policies and internal institutional policies may also limit F&A recovery. In addition to the administrative requirements mandated by OMB circulars, universities must also satisfy other Federal, state, and local laws and regulations regarding the conduct of research. These laws and regulations govern practices in many areas, including hazardous waste, occupational safety, animal care, and the protection of human subjects and are associated with real administrative costs that most likely will affect F&A rates for universities that are below the 26 percent cap on administrative costs. Universities whose administrative expenses are already at or above the 26 percent cap may need to provide additional institutional resources for their research activities. See the previous sidebar, "The Composition of Institutional Academic R&D Funds," for further discussion of unreimbursed indirect costs.

5. **Options to reduce or control the rate of growth of Federal F&A reimbursement rates.** If changes were implemented to reduce F&A reimbursement, the resulting shift of costs to universities would be detrimental to the research enterprise by either reducing spending for research and education or being passed on to students through increased tuition rates. In addition, any enactment of the mechanisms to decrease indirect cost recovery that are discussed in the report could result in reduced investments in building and renovating scientific facilities, thus jeopardizing future research capability and the S&E workforce. For the specific options discussed to reduce F&A costs, see U.S. OSTP 2000, appendix B.

6. **Options for creating an F&A database.** Some existing databases capture some F&A data. However, no systematic method by which the Federal Government collects data on F&A rates and costs exists. Therefore, it would be advantageous to create and maintain a database for Federal research F&A data that could track Federal indirect cost rates and reimbursement. Such a database would permit analysis of the impact that changes in policies would have on indirect costs and on the Federal Government, researchers, and research institutions. Creating such a database would require an organization within the government to take responsibility for collecting and analyzing these data. A revision to Circular A-21 in August 2000, required institutions to use a standard format for F&A rate proposals submitted on or after July 1, 2001. Adoption of this standard format might prove useful in facilitating the future development of an F&A database.

In early 2001, OMB issued a memorandum clarifying its treatment of two indirect cost issues—voluntary uncommitted cost sharing and tuition remission costs. For a detailed discussion of the changes, see Gotbaum 2001. Most faculty-organized research effort is either charged directly to the sponsor or is considered mandatory or voluntary cost sharing and captured in the accounting system. Voluntary uncommitted cost sharing, university faculty effort over and above that which is committed and budgeted for in a sponsored agreement, is not generally captured in the accounting system. Some Federal Government officials have interpreted Circular A-21 to require that a proportionate share of F&A costs be assigned to the voluntary uncommitted cost sharing effort either by including an estimated amount in the organized research base (thereby lowering the F&A reimbursement rate) or by adjusting the allocation of facility costs related to this effort (thereby lowering the facility costs eligible for reimbursement). The burden associated with detailed reporting of voluntary uncommitted cost sharing may be a disincentive for universities to contribute additional time to a research effort. In addition, the imprecise nature of the data concerning the amount of involuntary uncommitted cost sharing has made it difficult to compute and use as part of rate negotiations between the Federal Government and universities. Consequently, the memorandum stated that "voluntary uncommitted cost sharing should be treated differently from committed effort and should not be included in the organized research base for calculating the F&A rate or reflected in any allocation of F&A costs" (Gotbaum 2001).

Circular A-21 states that "the dual role of students engaged in research and the resulting benefits to sponsored agreements are fundamental to the research effort and shall be recognized in the application of these principles." It further states that "tuition remission costs for students are allowable on sponsored awards provided that there is a bona fide employer-employee relationship between the student and the institution." This last statement has been interpreted by some government officials to mean that, for tuition remission costs to be allowable, students must be treated as employees of the university for tax purposes, which would mean that the students' tuition remission benefits must be treated as taxable wages. This misunderstanding generated a considerable amount of concern from universities and Federal research agencies. The OMB memorandum clarified this by indicating that Federal policy on the support of graduate students participating in research is to provide a reasonable amount of support (tuition remission and other support) on the basis of the individual's participation in the project and is not contingent on there being an employer-employee relationship for tax purposes.

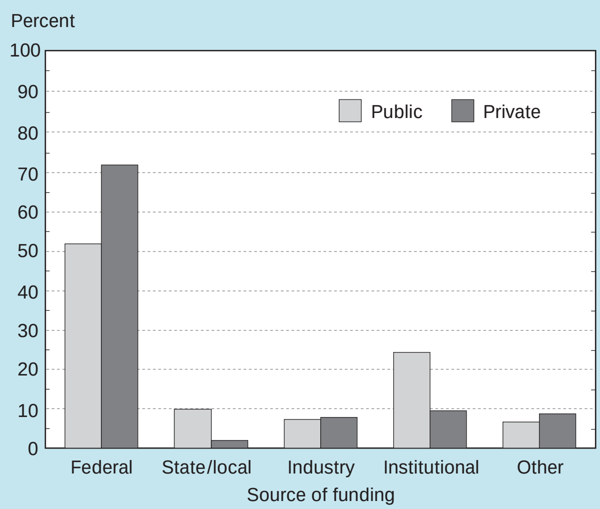
has steadily declined from 1.5 to 1.2 percent. (See appendix table 4-4 for time series data on industry-funded R&D.)

♦ **Other sources of funds.** In 2000, other sources of support accounted for 7 percent of academic R&D funding, a level that has stayed rather constant during the past three decades after declining from a peak of 10 percent in 1953. This category of funds includes grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to the conduct of research, as well as all other sources restricted to research purposes not included in the other categories.

Funding by Institution Type

Although public and private universities rely on the same funding sources for their academic R&D, the relative importance of those sources differs substantially for these two types of institutions. (See figure 5-6 and appendix table 5-3.) For all *public* academic institutions combined, slightly less than 10 percent of R&D funding in 1999, the most recent year for which data are available, came from state and local funds, about 24 percent from institutional funds, and about 52 percent from the Federal Government. *Private* academic institutions received a much smaller portion of their funds from state and local governments (about 2 percent) and institutional sources (10 percent), and a much larger share from the Federal Government (72 percent). The large difference in the role of institutional funds at public and private institutions is most likely due to a substantial amount of general-purpose state and local government funds that public institutions receive and decide to use for R&D (although data on such breakdowns are not collected). Both public and private institutions received approximately 7–8 percent of their respective R&D support from industry in 1999. Over the past two decades, the Federal share of support has declined, and the industry and institutional shares have increased for both public and private institutions.

Figure 5-6.
Sources of academic R&D funding for public and private institutions: 1999



See appendix table 5-3. *Science & Engineering Indicators – 2002*

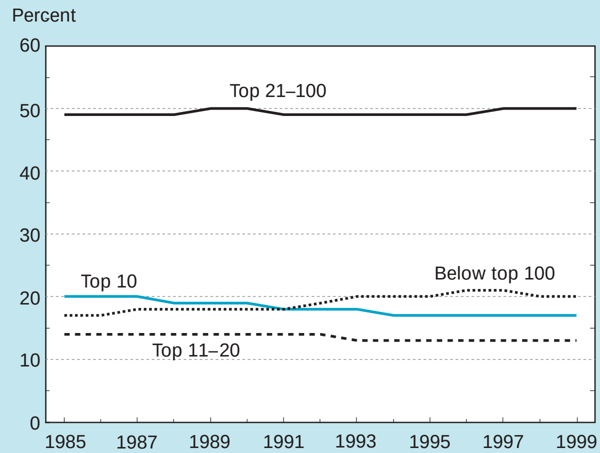
Distribution of R&D Funds Across Academic Institutions

The nature of the distribution of R&D funds across academic institutions has been and continues to be a matter of interest to those concerned with the academic R&D enterprise. Most academic R&D is now, and has been historically, concentrated in relatively few of the 3,600 U.S. institutions of higher education.[7] In fact, if all such institutions were ranked by their 1999 R&D expenditures, the top 200 institutions would account for about 96 percent of R&D expenditures. (See appendix table 5-4.) In 1999:

- the top 10 institutions spent 17 percent of total academic R&D funds ($4.6 billion),
- the top 20 institutions spent 30 percent ($8.3 billion),
- the top 50 spent 57 percent ($15.6 billion), and
- the top 100 spent 80 percent ($22.1 billion).

The historic concentration of academic R&D funds diminished somewhat between the mid-1980s and mid-1990s but has remained relatively steady since then. (See figure 5-7.) In 1985, the top 10 institutions received about 20 percent of the nation's total academic R&D expenditures and the top 11–20 institutions received 14 percent compared with 17 and 13 percent, respectively, in 1999. The composition of the universities in the top 20 has also fluctuated slightly from 1985 to 1999. There was almost no change in the share of the group of institutions ranked 21–100 during this period. The decline in the top 20 institutions' share was matched by the increase in the share of those institutions in the group below the top 100. This group's share increased from 17 to 20 percent of total academic R&D funds, signifying a broadening of the base. See "Spreading Institutional Base of Federally Funded Academic R&D" later in this chapter, under the section "Federal Support of Academic R&D," for a discussion of the increased number of academic institutions receiving Federal support for their R&D activities during the past three decades.

Figure 5-7.
Share of academic R&D of universities and colleges by rank of R&D expenditures: 1985–99



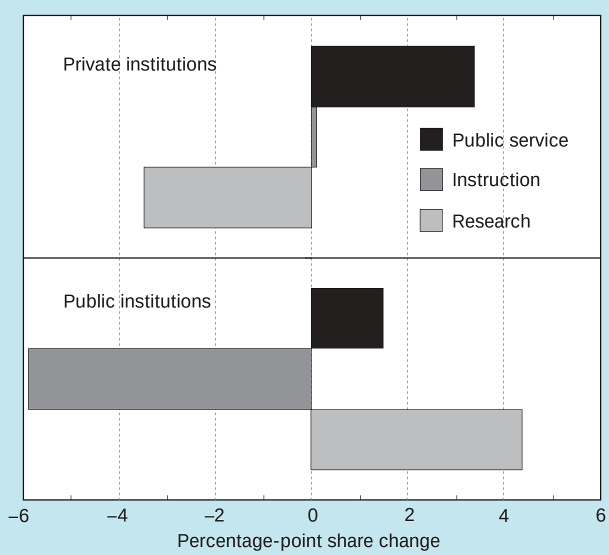
See appendix table 5-4. *Science & Engineering Indicators – 2002*

Emphasis on Research at Universities and Colleges

Between 1977 and 1996, the nation's universities and colleges increased their relative emphasis on research, as measured by research expenditures as a share of combined expenditures on instruction, research, and public service,[8] which are the three primary functions of academic institutions. This indicator rose from 19 to 21 percent during this period. This aggregate change, however, masks quite different trends at public and private institutions and among institutions with different Carnegie classifications. At public universities and colleges, the research expenditure share rose from 17 to 21 percent during this period, whereas at private institutions this share declined from 24 to 21 percent. (See figure 5-8 and appendix table 5-5.) The increased relative emphasis on research activity at public institutions was offset by a decline in emphasis on instruction. At private institutions, the declining relative emphasis on research was not offset by increased emphasis on instruction but by an increased emphasis on public service.

Although the increased emphasis on research in public institutions occurred in each of the four groups of institutions in Carnegie classes Research I and II and Doctorate-granting I and II, and the declining emphasis in research at private

Figure 5-8.
Changes in share of combined expenditures accounted for by research, instruction, and public service at public and private institutions: 1977–96



See appendix table 5-5. *Science & Engineering Indicators – 2002*

[7] The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories. These higher education institutions include four-year colleges and universities, two-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, etc.).

[8] *Public service* includes funds expended for activities that are established primarily to provide noninstructional services beneficial to individuals and groups external to the institution. These activities include community service programs and cooperative extension services.

institutions occurred in all four of these Carnegie classes, the extent of change was more substantial in some groups than in others. (See figure 5-9 and appendix table 5-6.) The increase in research emphasis in the public Doctorate-granting I group (6 to 13 percent) and the public Doctorate-granting II group (16 to 25 percent) were much larger than for the other two public groups. The decline for the private Research I class (42 to 36 percent) and the private Doctorate-granting II group (18 to 14 percent) were larger than for the other two groups.

Expenditures by Field and Funding Source

The distribution of academic R&D funds across S&E disciplines often is the unplanned result of numerous, sometimes unrelated, decisions and therefore needs to be monitored and documented to ensure that it remains appropriately balanced. The overwhelming share of academic R&D expenditures in 1999 went to the life sciences, which accounted for 57 percent of total academic R&D expenditures, 56 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures. (See appendix table 5-7.) Within the life sciences, the medical sciences accounted for 29 percent of total academic R&D expenditures and the biological sciences for 18 percent.[9] The next largest block of total academic R&D expenditures was for engineering—15 percent in 1999. The distribution of Federal and non-Federal funding of academic R&D in 1999 varied by field. (See appendix table 5-7.) For example, the Federal Government supported more than three-quarters of academic R&D expenditures in both physics and atmospheric sciences but one-third or less of academic R&D in economics, political science, and the agricultural sciences.

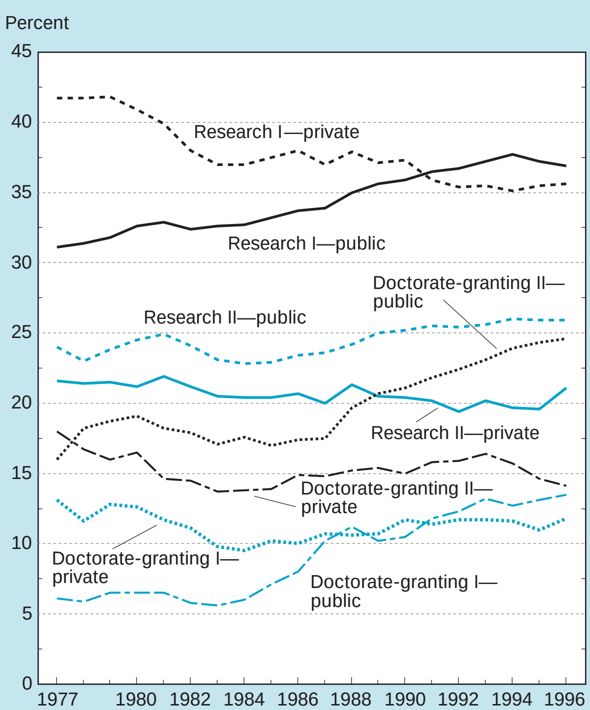
The declining Federal share in support of academic R&D is not limited to particular S&E disciplines. The federally financed fraction of support for *each* of the broad S&E fields was lower in 1999 than in 1973.[10] (See appendix table 5-8.) The most dramatic decline occurred in the social sciences, down from 57 percent in 1973 to 37 percent in 1999. The overall decline in Federal share also holds for all the reported fine S&E fields. However, most of the declines occurred in the 1980s, and most fields did not experience declining Federal shares during the 1990s.

Although academic R&D expenditures in constant 1996 dollars for every field increased between 1973 and 1999 (see figure 5-10 and appendix table 5-9), the R&D emphasis of

[9]The medical sciences include fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. The biological sciences include fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times, because boundaries between fields often are not well defined.

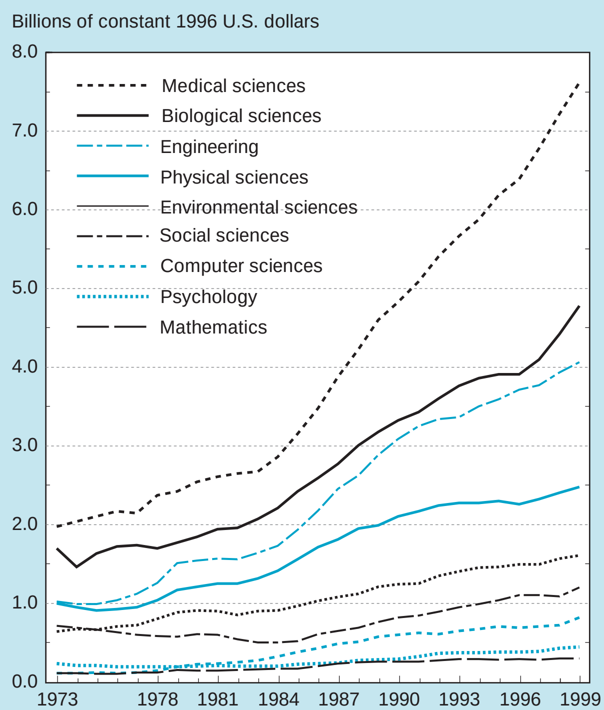
[10]In this chapter, the broad S&E fields refer to the physical sciences, mathematics, computer sciences, environmental sciences (earth, atmospheric, and ocean), life sciences, psychology, social sciences, other sciences (not elsewhere classified), and engineering. The more disaggregated fields of science and engineering are referred to as "fine fields" or "subfields."

Figure 5-9.
Research as percentage of the total of instruction, research, and public service expenditures, by Carnegie class and type of control: 1977–96



See appendix table 5-6. *Science & Engineering Indicators – 2002*

Figure 5-10.
Academic R&D expenditures, by field: 1973–99



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1996 dollars.

See appendix table 5-9. *Science & Engineering Indicators – 2002*

the academic sector, as measured by its S&E field shares, changed during this period.[11] (See figure 5-11.) Absolute shares of academic R&D have:

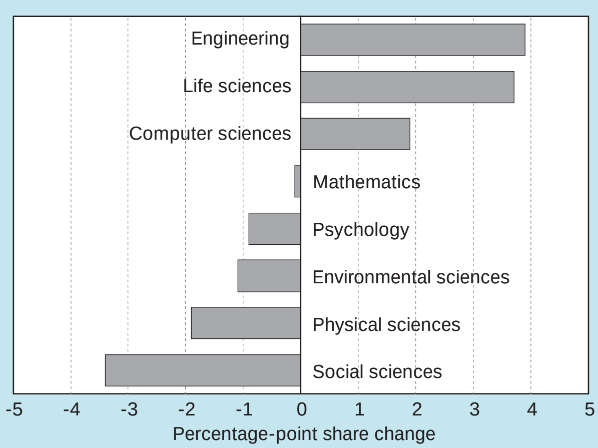
- increased for engineering, the life sciences, and the computer sciences;
- remained roughly constant for mathematics; and
- declined for psychology, environmental (earth, atmospheric, and ocean) sciences, physical sciences, and social sciences.

Although the proportion of the total academic R&D funds going to the life sciences increased by only 4 percentage points between 1973 and 1999, rising from 53 to 57 percent of academic R&D, the medical sciences' share increased by almost 7 percentage points, from 22 to 29 percent of academic R&D, during this period. (See appendix table 5-9.) The share of funds for each of the other two major components of the life sciences, agricultural sciences and biological sciences, decreased during the period. Engineering's share increased by almost 4 percentage points, from about 11.5 to 15.5 percent of academic R&D, while computer sciences' share increased by 2 percentage points, from 1 to 3 percent.

The social sciences' proportion of total academic R&D funds declined by more than 3 percentage points (from 8 to less than 5 percent) between 1973 and 1999. Within the social sciences, R&D shares for each of the three main fields, economics, political science, and sociology, declined over the period. Psychology's share declined by 1 percentage point (from 3 to 2 percent of academic R&D). The environmental sciences' share also declined by 1 percentage point (from 7 to 6 percent). Within the environmental sciences, the three major fields; atmospheric, earth, and ocean sciences, each experienced a decline in share. The physical sciences' share also declined during this period, from 11 to 9 percent. Within the physical sciences, however, astronomy's share increased, while the shares of both physics and chemistry declined.

[11]For a more detailed discussion of these changes, see *How Has the Field Mix of Academic R&D Changed?* (NSF 1998) and *Trends in Federal Support of Research and Graduate Education* (National Academies Board on Science, Technology and Economic Policy, forthcoming).

Figure 5-11.
Changes in share of academic R&D in selected S&E fields: 1973–99



See appendix table 5-9. *Science & Engineering Indicators – 2002*

Federal Support of Academic R&D

The Federal Government continues to provide the majority of the funding for academic R&D. Its overall contribution is the combined result of a complex set of Executive and Legislative branch decisions to fund a number of key R&D-supporting agencies with differing missions.

Some of the Federal R&D funds obligated to universities and colleges are the result of appropriations that Congress directs Federal agencies to award to projects that involve specific institutions. These funds are known as congressional earmarks. (See sidebar, "Congressional Earmarking to Universities and Colleges" for a discussion of this subject.) Examining and documenting the funding patterns of the key funding agencies is key to understanding both their roles and that of the government overall.

Top Agency Supporters

Three agencies are responsible for most of the Federal obligations for academic R&D are concentrated in three agencies: the National Institutes of Health (NIH), NSF, and the Department of Defense (DOD). (See appendix table 5-10.) Together, these agencies are estimated to have provided approximately 84 percent of total Federal financing of academic R&D in 2001: 60 percent by NIH, 15 percent by NSF, and 9 percent by DOD. An additional 11 percent of the 2001 obligations for academic R&D are estimated to be provided by the National Aeronautics and Space Administration (NASA) at 4 percent; the Department of Energy (DOE) at 4 percent; and the Department of Agriculture (USDA) at 3 percent. Federal obligations for academic research are concentrated similarly as those for R&D. (See appendix table 5-11.) Some differences exist, however, because some agencies (e.g., DOD) place greater emphasis on development, whereas others (e.g., NSF) place greater emphasis on research.

Between 1990 and 2001, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 4.9 percent per year in constant 1996 dollars. NSF and NASA experienced the next highest rates of growth: 4.2 and 3.1 percent, respectively.

Agency Support by Field

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field; the Department of Health and Human Services (HHS) and USDA focus on life sciences, whereas DOE concentrates on physical sciences. Other agen-

Congressional Earmarking to Universities and Colleges

Academic earmarking, the congressional practice of providing Federal funds to educational institutions for research facilities or projects without merit-based peer review, exceeded the billion-dollar mark for the first time ever in fiscal year (FY) 2000 and reached almost $1.7 billion in FY 2001.*

The lack of an accepted definition of academic earmarking, combined with the difficulty of detecting many earmarked projects because they are either obscured or described vaguely in the legislation providing the funding, often makes it difficult to obtain exact figures for either the amount of funds or the number of projects specifically earmarked for universities and colleges. Even with these difficulties, however, a number of efforts have been undertaken during the past two decades to measure the extent of this activity.†

A report from the Committee on Science, Space, and Technology (U.S. House of Representatives 1993) that estimates trends in congressional earmarking indicated that the dollar amount of such earmarks increased from the tens to the hundreds of millions between 1980 and the early 1990s, reaching $708 million in 1992. (See text table 5-2.) In the report, the late Congressman George E. Brown, Jr., (D-CA) stated, "I believe that the rational, fair, and equitable allocation and oversight of funds in support of the nation's research and development enterprise is threatened by the continued increase in academic earmarks. To put it colloquially, a little may be okay, but too much is too much."

During the past decade, the *Chronicle of Higher Education* also tried to estimate trends in academic earmarking through its annual survey of Federal spending laws and the congressional reports that explain them. The *Chronicle's* latest analysis showed that after reaching a peak of $763 million in 1993, earmarked funds declined rather substantially over the next several years, reaching a low of $296 million in FY 1996. After 1996, however, earmarks began to increase once again, and this growth continued throughout the latter part of the 1990s. Congress directed Federal agencies to award at least $1.044 billion for such projects in FY 2000, a 31 percent rise over FY 1999's record total of $797 million (Brainard and Southwick 2000), and $1.668 billion in FY 2001, a 60 percent rise over FY 2000 (Brainard and Southwick 2001). A record number of new institutions received earmarks in FY 2000, and money was provided for institutions in every state except Delaware. Also, for the first time, Congress earmarked funds to a virtual university. Helping to drive the large increase in FY 2000 was a sharp rise in earmarks for construction projects, with more than $152 million being spent on brick-and-mortar projects on campuses, more than double the amount spent in FY 1999.

Text table 5-2.
Funds for Congressionally earmarked academic research projects: 1980–2001
(Millions of dollars)

Year	Earmarked funds	Year	Earmarked funds
1980	11	1991	470
1981	0	1992	708
1982	9	1993	763
1983	77	1994	651
1984	39	1995	600
1985	104	1996	296
1986	111	1997	440
1987	163	1998	528
1988	232	1999	797
1989	299	2000	1,044
1990	248	2001	1,668

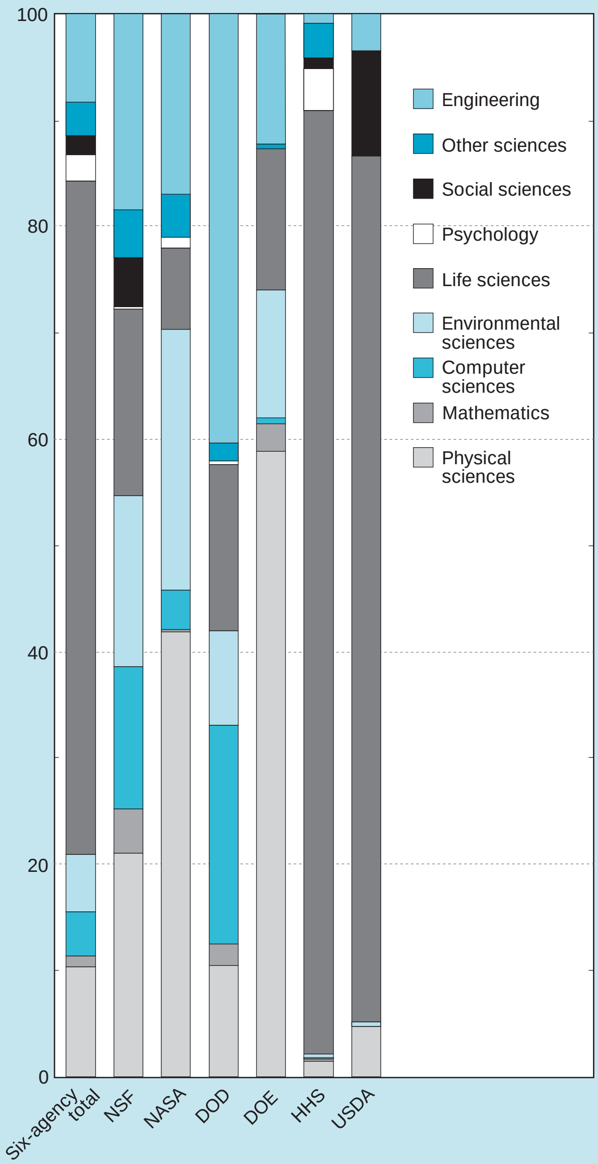
SOURCES: Data for 1980–92 are from the U.S. House of Representatives, Committee on Science, Space, and Technology, 1993; "Academic Earmarks: An Interim Report by the Chairman of the Committee on Science, Space, and Technology" (Washington, DC); data from 1993–2000 are from J. Brainard and R. Southwick, "Congress Gives Colleges a Billion-Dollar Bonanza in Earmarked Projects" (*The Chronicle of Higher Education,* Volume 46, July 28, 2000, p. A29); and data from 2001 are from J. Brainard and R. Southwick, "A Record Year at the Federal Trough: Colleges Feast on $1.67 Billion in Earmarks" (*The Chronicle of Higher Education,* Volume 47, August 10, 2001, p. A20).

Science & Engineering Indicators – 2002

* Not all of these funds go to projects that involve research. In FY 2001, an estimated 84 percent of the earmarked funds were for research projects, research equipment, or construction or renovation of research laboratories.

† In its FY 2001 budget submission to Congress (OMB 2001), OMB included a new category of Federal funding for research: research performed at congressional direction. This consists of intramural and extramural research in which funded activities are awarded to a single performer or collection of performers. There is limited or no competitive selection, or there is competitive selection but the research is outside the agency's primary mission, and undertaking the research is based on direction from the Congress in law, in report language, or by other direction. The total reported for this activity is $2.2 billion. The data are not disaggregated by type of performer.

Figure 5-12.
Distribution of Federal agency academic research obligations, by field: FY 1999

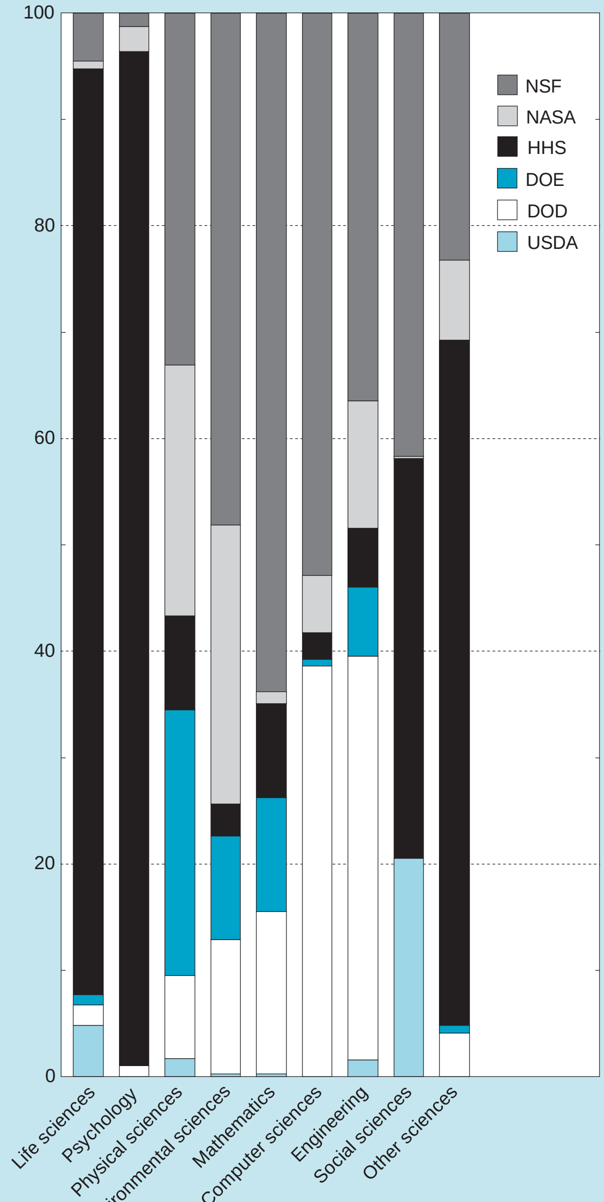


NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; USDA = Department of Agriculture

NOTE: Agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-12. *Science & Engineering Indicators – 2002*

Figure 5-13.
Major agency field shares of Federal academic research obligations: FY 1999



NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; HHS = Department of Health and Human Services; DOE = Department of Energy; DOD = Department of Defense; USDA = United States Department of Agriculture

NOTE: Agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-13. *Science & Engineering Indicators – 2002*

cies, NSF, NASA, and DOD, have more diversified funding patterns. (See figure 5-12 and appendix table 5-12.) Even though an agency may place a large share of its funds in one field, it may not be a leading contributor to that field, particularly if it does not spend much on academic research. (See figure 5-13.) In FY 1999, NSF was the lead funding agency in physical sciences (33 percent of total funding), mathematics (64 percent), computer sciences (53 percent), environmental sciences (48 percent), and social sciences (42 percent). DOD was the lead funding agency in engineering (38 percent). HHS was the lead funding agency in life sciences (87 percent) and psychology (95 percent). Within the fine S&E

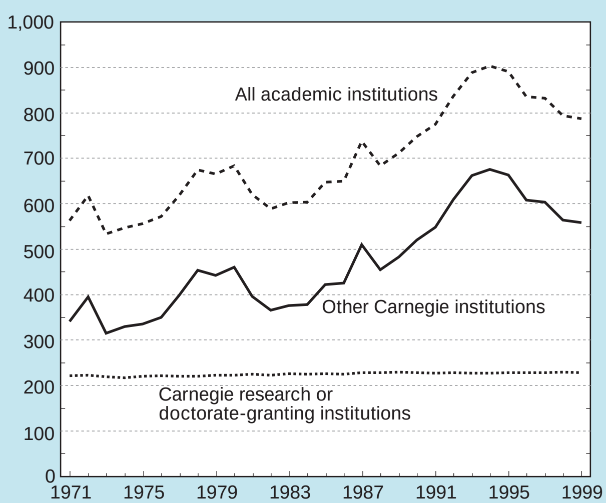
fields, other agencies took the leading role: DOE in physics (44 percent), USDA in agricultural sciences (100 percent), and NASA in astronomy (78 percent) and both aeronautical (55 percent) and astronautical (97 percent) engineering. (See appendix table 5-13.)

Spreading Institutional Base of Federally Funded Academic R&D

Since 1994, the number of academic institutions receiving Federal support for their R&D activities has declined. This decline followed a 20-year period in which there was a general upward trend in the number of institutions receiving such support.[12] (See figure 5-14.) The change in number has occurred almost exclusively among institutions of higher education not classified as Carnegie research or doctorate-granting institutions but in those classified as comprehensive; liberal arts; two-year community, junior, and technical; or professional and other specialized schools. The number of such institutions receiving Federal support nearly doubled between 1971 and 1994, rising from 341 to 676, but then dropped to only 559 in 1999. (See appendix table 5-14.) The institutions that were not classified as Carnegie research or doctorate-granting institutions also received a larger share of the reported Federal obligations for R&D to universities and colleges in the 1990s than they have at any time in the past. Their share even continued to increase during the latter part of the 1990s, reaching almost 14 percent in 1999. The largest percentage this group had received before the 1990s was just under 11 percent in 1977. This increase in share is consistent with the increase in the share of academic R&D going to institutions below the top 100 reported earlier in this chapter in "Distribution of R&D Funds Across Academic Institutions."

[12]Although there was a general increase in the number of institutions receiving Federal R&D support between 1974 and 1994, a rather large decline occurred in the early 1980s that was most likely due to the fall in Federal R&D funding for the social sciences during that period.

Figure 5-14.
Number of academic institutions receiving Federal R&D support by selected Carnegie classifications: 1971–99



NOTES: See "Carnegie Classification of Academic Institutions," in chapter 2 for information on the institutional categories used by the Carnegie Foundation for the Advancement of Teaching. "Other Carnegie institutions" are all institutions except Carnegie research and doctorate-granting institutions.

See appendix table 5-14. *Science & Engineering Indicators – 2002*

Academic R&D Facilities and Equipment

The condition of the physical infrastructure for academic R&D, especially the state of research facilities and equipment, is a key factor in the continued success of the U.S. academic R&D enterprise. The National Science Board's (NSB's) concern that the quality and adequacy of the S&E infrastructure are critical to maintaining U.S. leadership in S&E research and education recently led it to establish a task force to examine this issue. (See sidebar, "The NSB Task Force on S&E Infrastructure.")

Facilities

Total Space. The amount of academic S&E research space[13] grew continuously over the past decade. Between 1988 and 1999, total academic S&E research space increased by almost 35 percent, from about 112 million to 151 million net assignable square feet (NASF).[14] (See appendix table 5-15.) Doctorate-granting institutions accounted for most of the growth in research space over this period.

Little change was noted in the distribution of academic research space across S&E fields between 1988 and 1999. (See appendix table 5-15.) About 90 percent of current academic research space continues to be concentrated in six S&E fields:

- ♦ biological sciences (21 percent in 1988 and 1999),
- ♦ medical sciences (17 percent in 1988 and 18 percent in 1999),
- ♦ agricultural sciences (16 percent in 1988 and 17 percent in 1999),
- ♦ engineering (14 percent in 1988 and 17 percent in 1999),
- ♦ physical sciences (14 percent in 1988 and 13 percent in 1999), and
- ♦ environmental sciences (5 percent in 1988 and 1999).

New Construction. Between 1986–87 and 1998–99, the total anticipated cost for completion of new construction projects for academic research facilities begun in each two-year period fluctuated between $2 and $3 billion. (See appendix table 5-16.) Projects planned for 2000 and 2001, however, are expected to cost $7.4 billion by the time they are completed, and those begun in 1998 and 1999 are expected to cost $2.8 billion (reported in 1999 survey). Earlier in the planning

[13] For more detailed data and analysis on academic S&E research facilities (e.g., by institution type and control), see NSF (2001d,e).

[14] "Research space" here refers to NASF within facilities (buildings) in which S&E research activities take place. NASF is defined as the sum of all areas (in square feet) on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as instruction or research. Multipurpose space within facilities (e.g., an office) is prorated to reflect the proportion of use devoted to research activities. NASF data for new construction and repair/renovation are reported for combined years (e.g., 1987–88 data are for FY 1987 and FY 1988). NASF data on total space are reported at the time of the survey and were not collected in 1986.

stage, however, projects expected to begin in 1998 and 1999 were expected to cost $3.9 billion (reported in the previous S&E Facilities survey). Construction projects initiated between 1986 and 1999 were expected to produce more than 72 million square feet of research space when completed, the equivalent of about 48 percent of estimated 1999 research space. A significant portion of newly created research space is likely to replace obsolete or inadequate space rather than actually increase existing space, indicated by the total research space increase of 39 million NASF between 1988–89 and 1999, a period in which new construction activity was expected to produce 62 million NASF. (See appendix table 5-15.)

The ratio of planned new construction during the 1986–99 period to 1999 research space differs across S&E fields. More than three-quarters of the research space in medical sciences at medical schools and in computer sciences appears to have been built in the 1986–99 period. In contrast, less than one-quarter of the research space for mathematics and psychology appears to have been newly constructed during this period. (See figure 5-15.)

Repair and Renovation. The total cost of repair/renovation projects has also fluctuated over time. Expenditures for major repair/renovation (i.e., projects costing more than $100,000) of academic research facilities begun in 1998–99 are expected to reach $1.7 billion. (See appendix table 5-16.) Projects initiated between 1986 and 1999 were expected to result in the repair/renovation of more than 87 million square feet of research space.[15] (See appendix table 5-15.) Repair/renovation expenditures as a proportion of total capital expenditures (construction and repair/renovation) have increased

The NSB Task Force on S&E Infrastructure

The National Science Board is responsible for monitoring the health of the national research and education enterprise. Within the past year, NSB determined that the status of the national infrastructure for fundamental science and engineering should be assessed to ensure its future quality and availability to the broad S&E community. The Board believed that the S&E infrastructure had grown and changed and that the needs of the S&E community had evolved since the last major assessments were conducted more than a decade ago. Several trends contributed to the need for a new assessment, including:

- the impact of new technologies on research facilities and equipment;
- changing infrastructure needs in the context of new discoveries, intellectual challenges, and opportunities;
- the impact of new tools and capabilities such as information technology and large databases;
- the rapidly escalating cost of research facilities;
- changes in the university environment affecting support for S&E infrastructure development and operation; and
- the need for new strategies for partnering and collaboration.

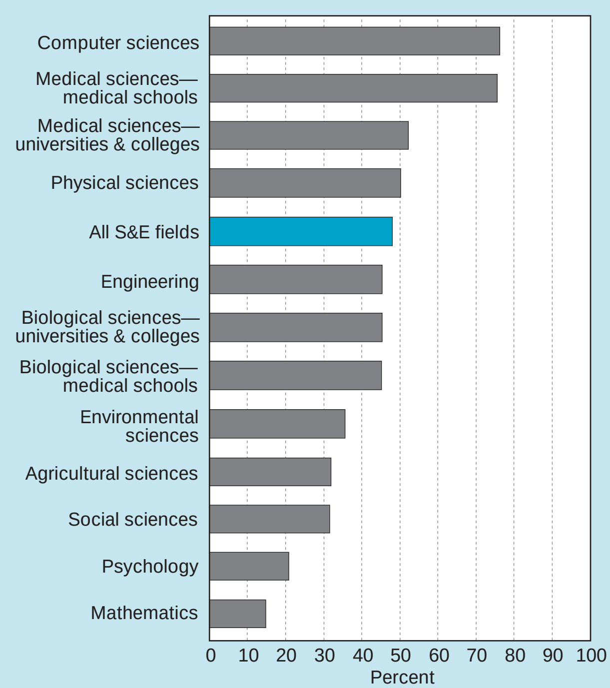
An NSB Task Force on S&E Infrastructure was established to undertake and guide the assessment. The task force was asked to assess the current status of the national S&E infrastructure, the changing needs of science and engineering, and the requirements for a capability of appropriate quality and size to ensure continuing U.S. leadership. Among the specific issues the task force was asked to consider were the following:

- appropriate strategies for sharing infrastructure costs for both development and operations among different sectors, communities, and nations;
- partnering and use arrangements conducive to ensuring the most effective use of limited resources and the advancement of discovery;
- the balance between maintaining the quality of existing facilities and the creation of new ones; and
- the process for establishing priorities for investment in infrastructure across fields, sectors, and Federal agencies.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

[15] It is difficult to report repaired/renovated space in terms of a percentage of existing research space. As collected, the data do not differentiate between repair and renovation, nor do they provide an actual count of unique square footage that has been repaired or renovated. Thus, any proportional presentation might include double or triple counts, because the same space could be repaired (especially) or renovated several times.

Figure 5-15.
New construction of research space planned during the 1986–99 period as a percentage of 1999 research space, by S&E field



See appendix table 5-15. *Science & Engineering Indicators – 2002*

steadily since 1990–91, rising from 22 percent of all capital project spending to 37 percent by 1998–99.

Sources of Funds. Academic institutions derive their funds for new construction and repair/renovation of research facilities from a number of sources: the Federal Government, state and local governments, institutional funds, private donations, tax-exempt bonds, other debt sources, and other sources. (See appendix tables 5-17 and 5-18.) In most years, state and local governments have provided a larger share of support than either private donations or tax-exempt bonds, followed by institutional funds. The Federal Government has never provided more than 14.1 percent of the funds for construction and repair/renovation. In 1998–99, the latest year for which data are available:

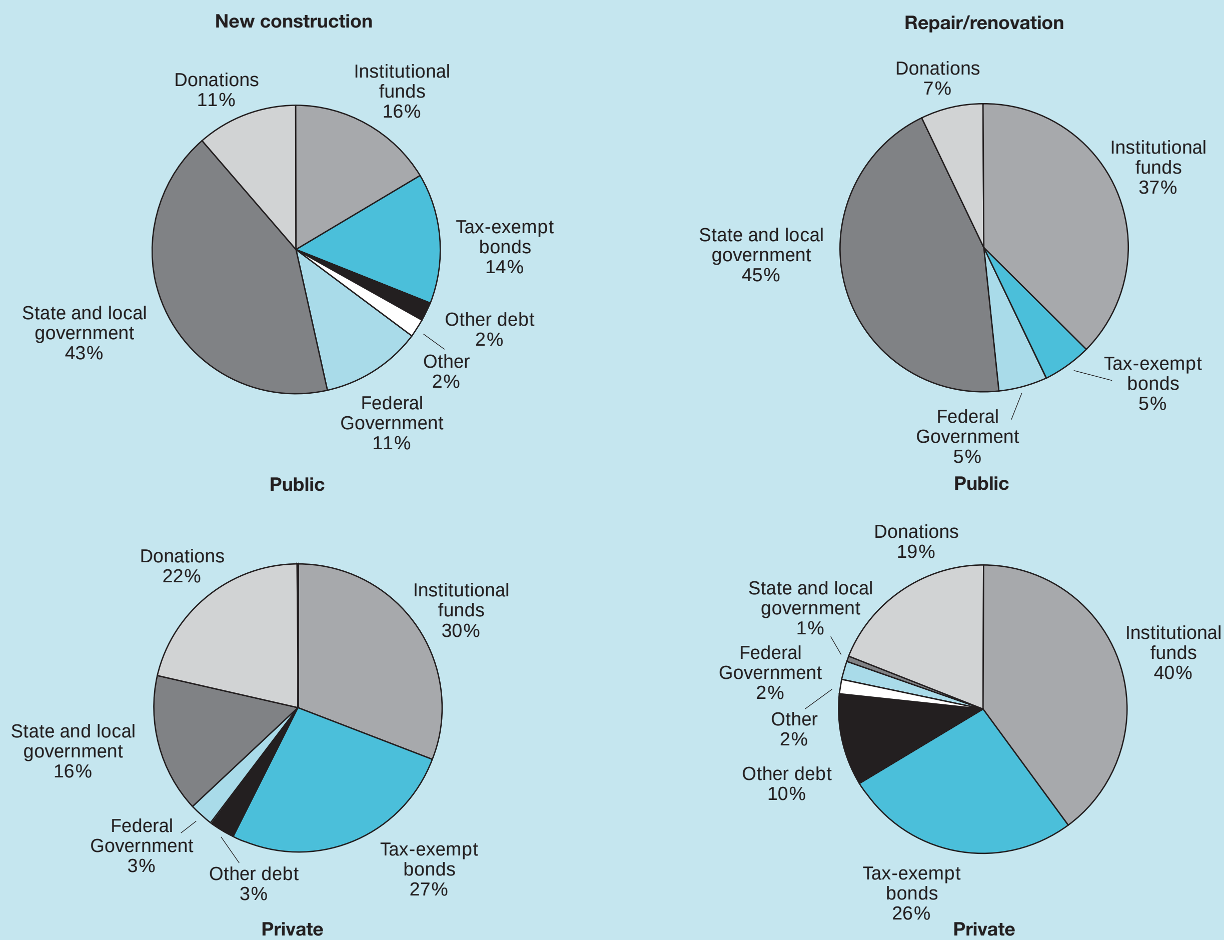
- the Federal Government directly accounted for only 8 percent of all construction funds and 4 percent of repair/renovation funds,[16]
- state and local governments accounted for 32 percent of all construction funds and 26 percent of repair/renovation funds,
- private donations accounted for 15 percent of all construction funds and 12 percent of repair/renovation funds,
- institutional funds accounted for 22 percent of all construction funds and 38 percent of repair/renovation funds, and
- tax-exempt bonds accounted for 19 percent of all construction funds and 14 percent of repair/renovation funds.

Public and private institutions drew on substantially different sources to fund the construction and repair/renovation of research space. (See figure 5-16) Public institutions relied primarily on:

- state and local governments (43 percent of funds for new construction and 45 percent of funds for repair/renovation),
- private donations (11 percent of funds for new construction and 7 percent of funds for repair/renovation),
- institutional funds (16 percent of funds for new construction and 37 percent of funds for repair/renovation), and

[16] Some additional Federal funding comes through overhead on grants and/or contracts from the Federal Government. These indirect cost payments are used to defray the overhead costs of conducting federally funded research and are reported as institutional funding on the NSF facilities survey. See the sidebar, "Recent Developments on the Indirect Cost Front," earlier in this chapter.

Figure 5-16.
Sources of funds for new construction and repair/renovation of research facilities at public and private universities and colleges: 1999



NOTE: Shares may not add to 100 percent because of rounding.

See appendix tables 5-17 and 5-18.

Science & Engineering Indicators – 2002

◆ tax-exempt bonds (15 percent of funds for new construction and 5 percent of funds for repair/renovation).

Private institutions relied primarily on:

◆ private donations (22 percent of funds for new construction and 19 percent of funds for repair/renovation),

◆ institutional funds (30 percent of funds for new construction and 40 percent of funds for repair/renovation), and

◆ tax-exempt bonds (27 percent of funds for new construction and 26 percent for repair/renovation).

Adequacy and Condition. Of the institutions reporting research space in 1999, more than 30 percent reported needing additional space in biological sciences in universities and colleges (as opposed to medical schools), physical sciences, psychology, and computer sciences. In all four of these fields, more than 25 percent of these institutions reported needing additional space equal to more than 25 percent of their current research space. (See text table 5-3.) Less than 20 percent of the institutions reported needing any additional space in medical sciences in both medical schools and universities and colleges, in biological sciences in medical schools, and in agricultural sciences.

Survey respondents also rated the condition of their research space in 1999. Slightly more than 40 percent of S&E research space was rated as "suitable for the most scientifically competitive research." (See text table 5-4.) However, 20 percent of the research space was designated as needing major repair/renovation and an additional 6 percent as needing replacement. The condition of this space differs across S&E fields. Fields with the largest proportion of research space needing major repair/renovation or replacement include agricultural sciences (33 percent), environmental sciences, biological sciences in universities and colleges, medical sciences in universities and colleges, and medical sciences in medical schools (each with between 26 and 28 percent).

Unmet Needs. Determining what universities and colleges need for S&E research space is a complex matter. To attempt to measure "real" as opposed to "speculative" needs, the survey asked respondents to report whether there was an approved institutional plan that included any deferred space needing new construction or repair/renovation.[17] Respondents were then asked to estimate, for each S&E field, the costs of such construction and repair/renovation projects and, separately, the costs for similar projects not included in an approved institutional plan.

In 1999, 44 percent of the institutions reported the existence of institutional plans that included deferred capital projects to construct or repair/renovate academic S&E research facilities. Twenty-five percent of institutions reported deferred projects not included in institutional plans. The total estimated cost for all deferred S&E construction and repair/renovation projects (whether included in an institutional plan or not) was $13.6 billion in 1999. Deferred construction projects accounted for 65 percent of this cost and deferred repair/renovation projects for the remaining 35 percent.

Deferred construction costs were close to or exceeded $1 billion in three fields: medical sciences in medical schools, biological sciences in universities and colleges, and engineering. Institutions reported deferred repair/renovation costs in excess of $500 million in the same three fields and in one additional field, as follows: medical sciences in medical

[17] Four criteria are used to define deferred space in a survey cycle: (1) the space must be necessary to meet the critical needs of current faculty or programs; (2) construction must not have been scheduled to begin during the two fiscal years covered by the survey; (3) construction must not have funding set aside for it; and (4) the space must not be for developing new programs or expanding the number of faculty positions.

Text table 5-3.
Adequacy of the amount of S&E research space, by field: 1999

Field	Percentage of institutions needing additional space: Less than 10 percent of current space	10–25 percent of current space	More than 25 percent of current space
Physical sciences	5.0	10.7	27.6
Mathematics	1.5	2.5	17.2
Computer sciences	0.6	3.6	28.4
Environmental sciences	3.9	5.2	18.2
Agricultural sciences	2.4	2.2	4.4
Biological sciences: universities and colleges	5.8	10.4	32.7
Biological sciences: medical schools	1.8	2.9	8.3
Medical sciences: universities and colleges	2.1	4.0	13.5
Medical sciences: medical schools	0.9	4.1	10.3
Psychology	2.4	6.9	25.8
Social sciences	3.6	4.5	19.8
Other sciences	1.5	0.3	1.6
Engineering	5.3	5.8	18.2

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Science and Engineering Research Facilities: 1999*, NSF 01-330 (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

Text table 5-4.
Condition of academic S&E research facilities, by field: 1999
(Percentage of S&E research space)

Field	Suitable for use in the most scientifically competitive research	Suitable for most levels of research	Requires major repair/renovation to be used effectively	Requires replacement
All S&E	40.9	33.2	19.7	6.2
Physical sciences	40.5	35.7	19.2	4.6
Mathematics	52.4	32.9	11.7	3.1
Computer sciences	42.7	34.7	15.4	7.2
Environmental sciences	38.7	34.2	21.0	6.0
Agricultural sciences	32.6	34.4	23.0	10.1
Biological sciences: universities and colleges	41.2	30.4	22.2	6.2
Biological sciences: medical schools	47.9	28.5	17.5	6.1
Medical sciences: universities and colleges	31.1	42.6	20.0	6.3
Medical sciences: medical schools	43.7	28.3	21.4	6.6
Psychology	38.5	38.7	18.6	4.2
Social sciences	43.3	38.5	14.7	3.4
Engineering	43.1	35.1	17.0	4.8

NOTE: Components may not add to 100 percent because of rounding. Quality was assessed relative to current research program.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities: 1999*, NSF 01-330 (Arlington, VA, 2001).

Science & Engineering Indicators – 2002

schools ($1.6 billion for construction and 0.5 billion for repair/renovation); biological sciences in universities and colleges ($1.5 billion for construction and $0.7 billion for repair/renovation); engineering ($1.0 billion for construction and $0.8 billion for repair/renovation); and physical sciences ($0.7 billion for construction and $1.0 billion for repair/renovation). (See appendix table 5-19.)

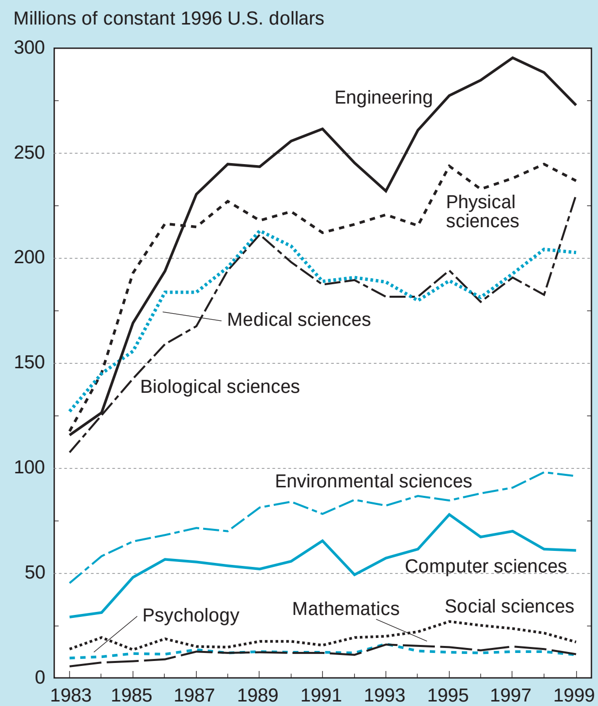
Equipment

Expenditures. In 1999, slightly more than $1.3 billion in current funds was spent for academic research equipment. About 80 percent of these expenditures were concentrated in three fields: life sciences (41 percent), engineering (22 percent), and physical sciences (19 percent). (See figure 5-17 and appendix table 5-20.)

Current fund expenditures for academic research equipment grew at an average annual rate of 4.2 percent (in constant 1996 dollars) between 1983 and 1999. Average annual growth, however, was much higher during the 1980s (8.7 percent) than it was during the 1990s (0.8 percent). The growth patterns in S&E fields varied during this period. For example, equipment expenditures for engineering (5.5 percent) grew more rapidly during the 1983–99 period than did those for the social sciences (1.4 percent) and psychology (1 percent).

Federal Funding. Federal funds for research equipment are generally received either as part of research grants, thus enabling the research to be performed, or as separate equipment grants, depending on the funding policies of the particular Federal agencies involved. The importance of Federal funding for research equipment varies by field. In 1999, the social sciences received slightly less than 40 per-

Figure 5-17.
Current fund expenditures for research equipment at academic institutions, by field: 1983–99



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1996 dollars.

See appendix table 5-20. *Science & Engineering Indicators – 2002*

cent of their research equipment funds from the Federal Government; in contrast, Federal support accounted for more than two-thirds of equipment funding in the physical sciences, computer sciences, and environmental sciences. (See appendix table 5-21.)

The share of research equipment expenditures funded by the Federal Government declined from 62 to 58 percent between 1983 and 1999, although not steadily. This overall pattern masks different trends in individual S&E fields. For example, the share funded by the Federal Government actually rose during this period for both the social and the environmental sciences.

R&D Equipment Intensity. R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This proportion was lower in 1999 (5 percent) than it was in 1983 (6 percent), although it peaked in 1986 (7 percent). (See appendix table 5-22.) R&D equipment intensity varies across S&E fields. It tends to be higher in physical sciences (about 10 percent in 1999) and lower in social sciences (1 percent) and psychology (2 percent). For the two latter fields, these differences may reflect the use of less equipment, less expensive equipment, or both.

Doctoral Scientists and Engineers in Academia

U.S. universities and colleges are central to the nation's scientific and technological prowess. They generate new knowledge and ideas that form the basis of innovation that is vital to the advancement of science. In the process, they produce the highly trained talent needed to exploit and refresh this new knowledge. In addition, academia increasingly plays an active part in the generation and exploitation of new products, technologies, and processes.

The confluence of these key functions: the pursuit of new knowledge, the training of the people in whom it is embodied, and its exploitation toward generating innovation, makes academia a national resource whose vitality rests in the scientists and engineers who work there. Especially important are those with doctoral degrees who do the research, teach and train the students, and stimulate or help to produce innovation. Who are they, how are they distributed, what do they do, how are they supported, and what do they produce?[18]

Employment and research activity at the 125 largest research-performing universities in the United States are a special focus of analysis.[19] These institutions have a disproportionate influence on the nation's academic science, engineering, and R&D enterprise. They enroll 22 percent of full-time undergraduates and award one-third of all bachelors' degrees, but 40 percent of those in S&E; their baccalaureates, in turn, are the source of 54 percent of the nation's S&E doctoral degree-holders and more than 60 percent of those in academia with R&D as their primary work function. Their influence on academic R&D is even larger: they conduct more than 80 percent of it (as measured by expenditures), and they produce the bulk of academic article outputs and academic patents. For these reasons, they merit special attention.

Growth in academic employment over the past half century reflected both the need for teachers, driven by increasing enrollments, and an expanding research function, largely supported by Federal funds. Trends in indicators relating to research funding have been presented above, this section presents indicators about academic personnel. Because of the intertwined nature of academic teaching and research, much of the discussion deals with the overall academic employment of doctoral-level scientists and engineers, specifically the relative balance between faculty and nonfaculty positions, demographic composition, faculty age structure, hiring of new Ph.D.s, trends in work activities, and trends in Federal support. The section also includes a discussion of different estimates of the nation's academic R&D workforce and effort and considers whether a shift away from basic research toward more applied R&D functions has occurred.

Academic Employment of Doctoral Scientists and Engineers

Universities and colleges employ less than half of doctoral scientists and engineers.[20] Academic employment of S&E doctorate holders reached a record high of 240,200 in 1999, approximately twice their number in 1973. Long-term growth of these positions was markedly slower than that in business, government, and other segments of the economy. The academic doubling compares with increases of 230 percent for private companies, 170 percent for government, and 190 percent for all other segments. As a result, the academic employment share dropped from 55 to 45 percent during the 1973–99 period.

Within academia, growth was slowest for the major research universities. Text table 5-5 shows average annual growth rates for S&E Ph.D.-holders in various segments of the U.S. economy; appendix table 5-23 breaks down academic employment by type of institution.

Foreign-Born Academic Scientists and Engineers

An increasing number (nearly 30 percent) of Ph.D.-level scientists and engineers at U.S. universities and colleges are foreign-born. Like other sectors of the economy, academia has long relied extensively on foreign talent among its faculty, students, and other professional employees; this reliance increased during the 1990s. By a conservative estimate, for-

[18]The academic doctoral S&E workforce includes full and associate professors (referred to as "senior faculty"); assistant professors and instructors (referred to as "junior faculty"); and lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates. S&E fields are defined by field of Ph.D. degree. All numbers are estimates rounded to the nearest 100. The reader is cautioned that small estimates may be unreliable.

[19]This set of institutions comprises the Carnegie Research I and II universities, based on the following 1994 classification: institutions with a full range of baccalaureate programs, commitment to graduate education through the doctorate, annual award of at least 50 doctoral degrees, and receipt of Federal support of at least $15.5 million (1989–91 average); see Carnegie Foundation for the Advancement of Teaching (1994). The classification has since been modified, but the older schema is more appropriate to the discussion presented here.

[20] Unless specifically noted, data on doctoral scientists and engineers refer to persons with doctorates from U.S. institutions, surveyed biannually by NSF in the *Survey of Doctorate Recipients.*

Text table 5-5.
Average growth rates for employment of doctoral scientists and engineers in the U.S. economy
(Percent)

Sector	1973–81	1981–91	1991–99
All sectors	5.7	3.4	2.3
Academia, total	4.4	2.8	1.7
Research universities	4.3	2.6	0.6
All others	4.7	3.0	2.7
Business	8.2	2.2	4.4
Government	5.0	2.3	4.9
All others	6.7	8.6	–3.4

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), Survey of Doctorate Recipients.

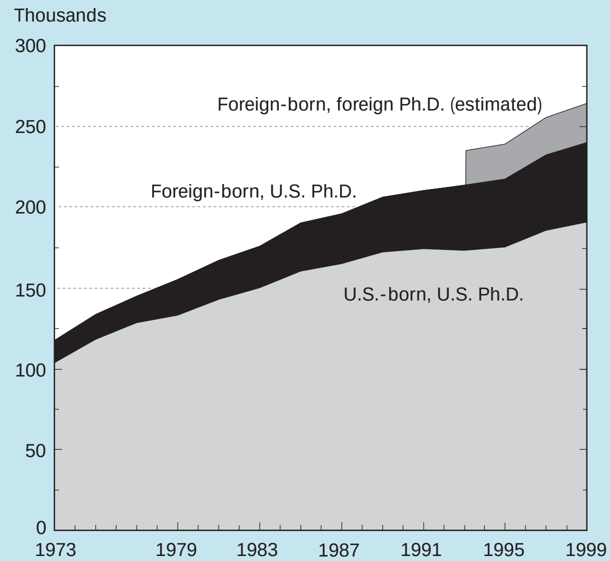
Science & Engineering Indicators – 2002

eign-born Ph.D.-holders accounted for about 28 percent of the total number of academically employed doctoral scientists and engineers at the end of the decade. Figure 5-18 delineates the academic employment estimate of 240,200 U.S.-earned Ph.D.s into those awarded to U.S. citizens and those awarded to foreign-born individuals.

The figure also shows an estimate of 24,300 individuals with S&E doctorates from foreign universities for each of the survey years.[21] The number is derived from the relationship of foreign-earned degrees to all U.S.-earned Ph.D.s in 1993, which was based on a sample drawn from the full doctoral population in the United States at the time of the 1990 census. (See text table 5-6.) The estimate of 24,300 represents a lower-bound value. It fails to take into account the rising pace of immigration into the United States during the 1990s, the creation of special visa programs to provide increased access to U.S. employment, an increase in the propensity of foreign Ph.D.-holders to remain in the United States, and some contrary evidence of a possible rise in return flows of foreign nationals in the second half of the decade. No reliable quantitative data are available on which to base a more solid estimate of the effects of these developments on academic employment.

[21]The actual 1999 survey estimate of 17,400 is clearly an underestimate. It is based only on a sample of those who were in the country in 1990 and responded to a 1999 survey of doctorate degree-holders.

Figure 5-18.
Academic employment of U.S.-born and foreign-born doctoral scientists and engineers: 1973–99



NOTE: Data on foreign-born foreign-earned Ph.D.s unavailable for 1973–91.

See appendix table 5-24 and text table 5-6.

Science & Engineering Indicators – 2002

Text table 5-6.
Estimates of foreign-born Ph.D. scientists and engineers at U.S. universities and colleges

Source of doctorate and place of birth	1973	1983	1993	1995	1997	1999
Total Ph.D. scientists and engineers						
Estimate 1	NA	NA	235,347	237,716	250,680	257,598
Estimate 2	NA	NA	235,347	239,513	255,987	264,427
Ph.D.s earned in U.S. (total)	117,957	176,082	213,758	217,543	232,505	240,169
Born in U.S.	104,426	150,397	173,288	175,764	185,957	191,158
Foreign-born	13,531	25,685	40,470	41,779	46,548	49,011
Ph.D.s earned abroad (total)						
Estimate 1	NA	NA	21,589	20,174	18,175	17,428
Estimate 2	NA	NA	21,589	21,971	23,482	24,257
Percent foreign-born						
Estimate 1	NA	NA	26.4	26.1	25.8	25.8
Estimate 2	NA	NA	26.4	26.6	27.4	27.7

NA = not available

NOTE: Estimate 1 is derived from Scientists and Engineers Statistical Data System (SESTAT). Estimate 2 is derived by applying the 1993 ratio of non-U.S.- to U.S.-earned degrees from SESTAT to all years. Data for 1973, 1983, and 1993 U.S.-born includes all persons with unknown place of birth.

See appendix table 5-24.

Science & Engineering Indicators – 2002

Nevertheless, figure 5-18 suggests that participation by foreign-born doctorate-holders in U.S. academic S&E increased continuously during at least the past two decades. For those with U.S.-earned doctoral degrees, employment rose from 11.7 percent in 1973 to 20.4 percent in 1999; for postdoctorates, it is double that percentage. (See appendix table 5-24.) Adding the lower-bound estimate for those with foreign-earned degrees boosts these percentages from 26.4 percent in 1993 to 27.7 percent in 1999.

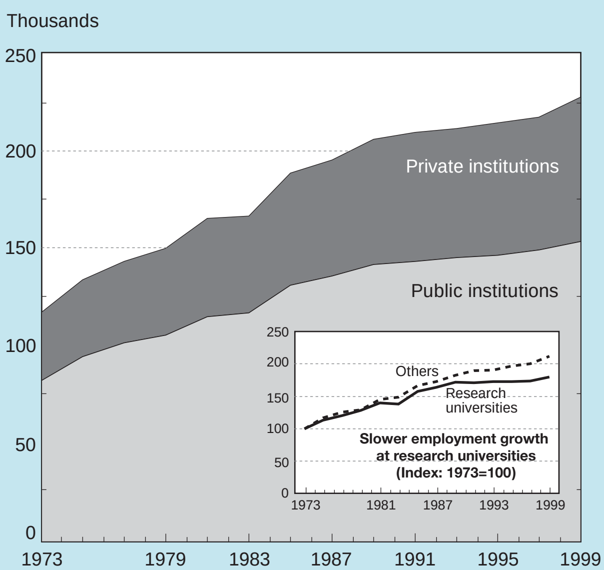
Slower Hiring at Research Universities and Public Institutions

Employment growth over the past decade was slower at the research universities than at other universities and colleges, after enjoying robust earlier increases.[22] (See appendix table 5-25.) From 1993 to 1999, doctoral S&E employment at research universities expanded by 3.8 percent. In contrast, employment at other institutions grew uninterruptedly for at least three decades, increasing by 10.8 percent during the 1990s, primarily during the second half of the decade. Figure 5-19 shows some of these employment trends.

During the 1990s, employment increased less rapidly at public universities and colleges than at their private counterparts (2.1 versus 8.0 percent for research universities; 9.3 versus 13.8 percent for others). Moreover, the much stronger growth in public universities and colleges outside the ranks of the research universities suggests that state governments are more interested in expanding the institutional segment that focuses on education and training than in raising the employment of the flagship institutions that conduct most of the research. (See appendix table 5-25.)

[22]Unless specifically stated, all subsequent analyses are based on U.S. doctorates only, since there is insufficient information on the faculty status of foreign-degreed Ph.D.-holders and on which academic institutions employ them.

Figure 5-19.
Doctoral scientists and engineers employed in public and private universities and colleges: 1973–99



See appendix table 5-25.

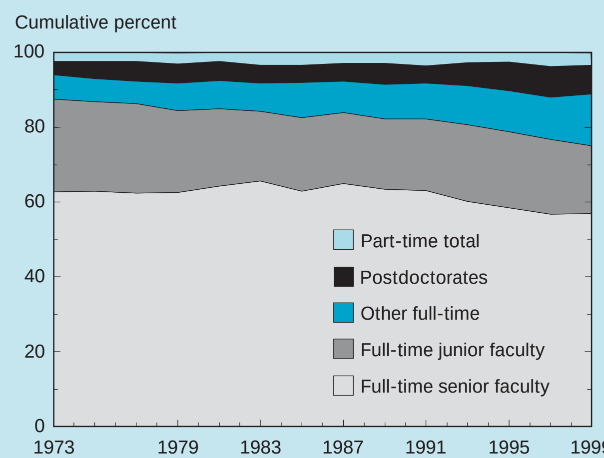
Science & Engineering Indicators – 2002

Declining Faculty Appointments, More Postdoctorate and Other Positions

The full-time tenured faculty position is being undermined as the academic norm by trends that accelerated in the 1990s. As faculty appointments decreased, appointments to postdoctorate and other types of positions increased. Overall, academic employment of doctoral scientists and engineers was quite robust, growing from 118,000 in 1973 to 240,200 in 1999. (See appendix table 5-26.) However, traditional faculty positions grew less rapidly, especially during the 1990s, when the number of senior faculty—full and associate professors—rose only modestly, and the number of junior faculty remained static. During that decade, full-time nonfaculty positions grew by half, as did postdoctorate appointments.

Figure 5-20 shows the resulting distribution in the structure of academic employment. The share of full-time senior faculty fell from 65 percent of total employment in the mid-1980s to only 57 percent in 1999, with particularly steep drops during the 1990s. The share of junior faculty also declined, bringing the overall faculty share to 75 percent of total employment, a steep loss from 88 percent in the early 1970s. The decline in the 1990s was linear, from 82 to 75 percent in fewer than 10 years. These employment trends in the past decade occurred as real academic R&D spending rose by half, retirement of faculty who had been hired during the expansionist 1960s increased, academic hiring of young Ph.D.-hold-

Figure 5-20.
Distribution of Ph.D. scientists and engineers, by type of academic appointment: 1973–99



NOTE: Junior faculty includes assistant professors and instructors; senior faculty includes full and associate professors.

See appendix table 5-25. *Science & Engineering Indicators – 2002*

ers showed a modest rebound, and universities placed a growing emphasis on the practical application of academic research results, discussed later in this chapter.[23]

Nonfaculty ranks, that is, full- and part-time adjunct faculty, lecturers, research and teaching associates, administrators, and postdoctorates, increased from 36,900 in 1989 to 59,800 in 1999. This 62 percent increase stood in sharp contrast to the 6 percent rise in the number of full-time faculty. Both the full-time nonfaculty and postdoctorate components both grew very rapidly between 1989 and 1999 (72 and 61 percent, respectively), while part-time employment rose 32 percent.[24] In fact, part-time employees accounted for between 2 and 4 percent of the total throughout the period. (See appendix table 5-26.)

Academic Employment Patterns for Recent Ph.D.-Holders

The trends just discussed reflect the pool of the entire academic workforce of S&E Ph.D.-holders. A sharper indication of current trends can be gleaned by looking at the academic employment patterns of those with recently awarded Ph.D.s, here defined as persons who earned their doctorates at U.S. universities within three years of the survey year.

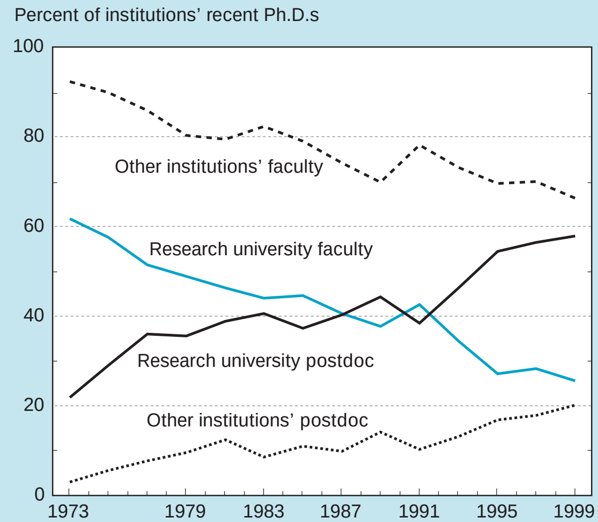
Recent Ph.D.-holders who enter academic employment today are more likely to receive postdoctorate appointments than faculty positions, which declined sharply over the past decade and have even undergone a reversal when viewed over the longer term. Those in research universities are more than twice as likely to be in postdoctorate appointments as to have faculty rank. (See appendix table 5-27 and figure 5-21.) Overall, since 1973, the percentage of recent Ph.D.-holders hired into full-time faculty positions has been cut nearly in half, from 74 to 37 percent. The decline at research universities has been sharper, from 60 to 24 percent. Conversely, the overall proportion of Ph.D.-holders who reported being in postdoctorate positions has risen from 13 to 43 percent (and from 21 to 58 percent at research universities). Those in public research institutions are somewhat more likely than those in private institutions to hold full-time faculty positions and somewhat less likely to have postdoctorate rank.

Similar Trends for Young Ph.D.s With a Track Record

For those in academia four to seven years after earning their doctorates, the picture looks quite similar: only two-thirds had attained faculty rank at that point compared with nearly 90 percent in the early 1970s, and the trend continues to point downward. (See appendix table 5-27.) Only about half were in tenure-track positions, with 10 percent already tenured, well below the experience of previous decades. Moreover, the overall proportion of those in a tenure track position, whether already tenured or not, has declined for the past two decades, and this trend shows no sign of abating.

Taken together, these data suggest a continuing shift, accelerating during the 1990s, toward forms of employment outside traditional tenure track positions. (See figure 5-22.) This shift toward nonfaculty employment touched most major fields. In fact, gains in the total number of full-time fac-

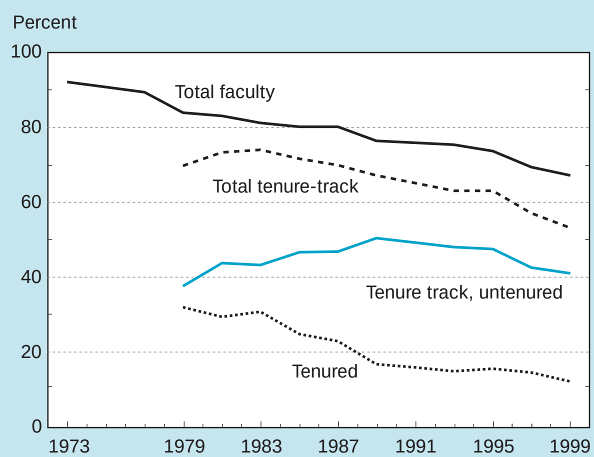
Figure 5-21.
Recent S&E Ph.D.s hired into faculty and postdoc positions at research universities and other academic institutions: 1973–99



NOTES: Recent Ph.D.s have earned doctorates within three years of the survey year. Those hired into other positions not shown.

See appendix table 5-27. *Science & Engineering Indicators – 2002*

Figure 5-22.
Faculty and tenure track-status of academic S&E Ph.D.s whose doctorate was earned 5–7 years earlier: 1973–99



SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

[23] It is impossible with the data at hand to establish causal connections among these developments.

[24] For more information on this subject, see "Postdoctorate Appointments" in chapter 3.

ulty positions were restricted to the life and computer sciences, with the other fields holding steady or registering only marginal increases. However, for every field except environmental (i.e., earth, atmospheric, and ocean) sciences, the proportion of total doctoral employment held by full-time faculty decreased. (See appendix table 5-26.)

Concerns About Retirement Behavior of Doctoral Scientists and Engineers

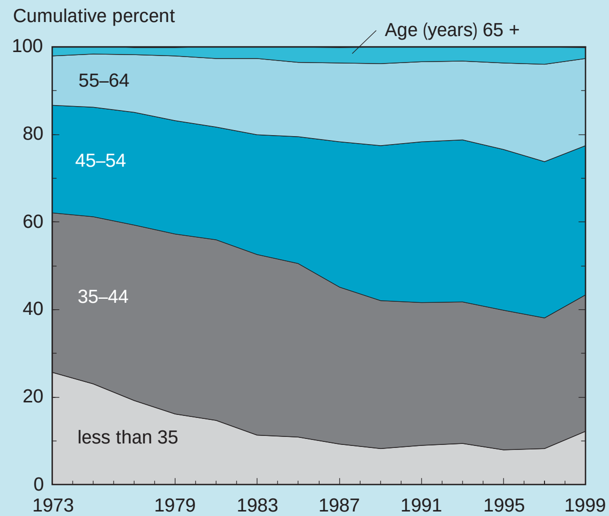
The trend toward fewer faculty appointments and more full-time nonfaculty and postdoctorate components is especially noteworthy because academia is in a period of increasing retirements. In the 1960s, the number of institutions, students, and faculty in the United States expanded rapidly, bringing many young Ph.D.-holders into academic faculty positions. This growth boom slowed sharply in the 1970s, and faculty hiring has since continued at a more modest pace. The result is that increasing numbers of faculty (and others in nonfaculty positions) are today reaching or nearing retirement age.[25]

A law defining age discrimination, the Age Discrimination in Employment Act, became fully applicable to universities and colleges in 1994.[26] It prohibits the forced retirement of faculty at any age, raising concerns about the potential ramifications of an aging professorate for scholarly productivity and the universities' organizational vitality, institutional flexibility, and financial health. These concerns were the focus of a National Research Council (NRC) (1991) study. The study concluded that "overall, only a small number of the nation's tenured faculty will continue working in their current positions past age 70" (NRC 1991, p. 29), but added: "At some research universities a high proportion of faculty would choose to remain employed past age 70 if allowed to do so" (NRC 1991, p. 38).

Sufficient data have now accumulated to allow examination of these concerns. Figure 5-23 shows the age distribution of academic doctoral scientists and engineers, and figure 5-24 displays the percentage of academic doctoral scientists and engineers 60 years of age or older. They show that the proportion of 60- to 64-year-olds was rising well before the act became mandatory, then leveled off. A similar progression can be seen for those age 65 or older, who made up 3 percent of the research universities' full-time faculty and 2 percent of other institutions' full-time faculty in 1999. The employment share of those older than age 70 rose during the last quarter century; it stood at 0.5 percent in 1999. (See appendix tables 5-28 and 5-29.)

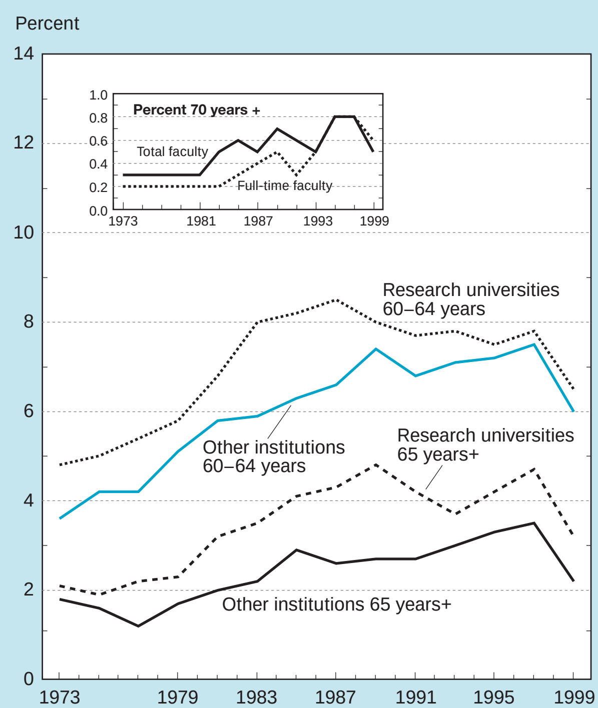
These data suggest that concerns that universities would continue to employ many unproductive professors have been

Figure 5-23.
Age distribution of full-time academic doctoral S&E faculty: 1973–99



See appendix table 5-29. *Science & Engineering Indicators – 2002*

Figure 5-24.
Full-time faculty age 60 and older at research universities and other higher education institutions: 1973–99



See appendix table 5-29. *Science & Engineering Indicators – 2002*

[25]See also the discussion of retirements from the S&E workforce in chapter 3, "Science and Engineering Workforce."

[26]A 1986 amendment to the Age Discrimination in Employment Act of 1967 prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993, allowing termination of employees with unlimited tenure who had reached age 70.

Text table 5-7.
Percentage of academic S&E doctorate holders leaving full-time employment in 1993–95 period, by number of articles published in previous five years

Age in 1995	Total	Number of articles: 0	1–5	6 or more
51–55	3.2	5.7	3.5	1.0
56–60	9.2	12.2	8.6	6.7
61–65	24.6	32.6	23.5	16.1
66–70	35.7	—	43.1	28.0
71–73	40.6	—	—	28.1

— = number of cases too small to estimate

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

misplaced. Further evidence is provided by examining the article output of those retiring at different ages, as shown in text table 5-7. The table compares the 1993–95 transition rates from full-time academic employment of S&E Ph.D.-holders with the number of articles they reported publishing over the previous five years. Within each age group, those with six or more articles were less likely to leave full-time employment than those with fewer or no articles.

Women and Minority Group Members As Faculty Role Models

The relatively large annual supply of new S&E doctorate-holders suggests that finding a sufficient number of replacement faculty may not be difficult. However, accumulating research points to the importance of role models and mentoring to student success in mathematics, science, and engineering, especially for women and minorities. These two groups make up a pool of potential scientists and engineers that has not been fully tapped and that, in the case of minorities, represents a growing share of U.S. youth, estimated to reach 45 percent of the college-age population by 2025. (See appendix table 2-2.) Thus, the presence of women and minority faculty on college campuses may well be one important factor in the recruitment of women and minorities to these fields. What have been the major hiring trends for them, and what is their current status?

Women

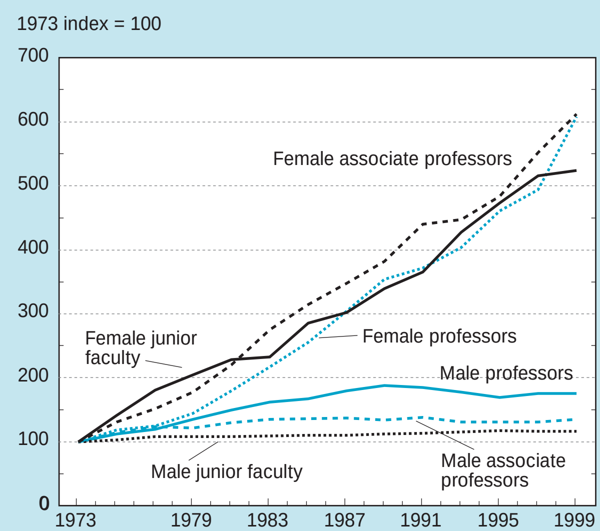
The academic employment of women with S&E doctorates has risen steeply over the past quarter century, reflecting the steady increase in the proportion of women among holders of newly awarded S&E doctorates. The number of women in academia increased sixfold between 1973 (when this type of employment information was first collected) and 1999, from 10,700 to an estimated 64,400, bringing their share from 9 to 27 percent. (See appendix table 5-30.) By the end of the decade, women constituted just under one-quarter of full-time faculty, up from 6 percent. Compared with men, women faculty remain relatively more heavily concentrated in life sciences and psychology, with correspondingly lower shares in engineering, physical sciences, and mathematics.

Women's growing share of academic employment reflects the confluence of three factors: their rising proportion among new doctorates, somewhat greater predilection for choosing an academic career, and being hired into these positions at somewhat higher rates than men. This historical dynamic is reflected in declining numbers of women as one moves up in faculty rank: in 1999, women constituted 12 percent of full professors, 25 percent of associate professors, and 37 percent of the junior faculty, the latter roughly in line with their recent share of Ph.D.s earned. (See the section "Doctoral Degrees by Sex" in chapter 2.) In contrast, the number of men increases as one moves from junior to senior faculty ranks. (See figure 5-25.) This contrasting pattern indicates the recent arrival of significant numbers of women doctorate-holders in full-time academic faculty positions. It suggests that the number of women among the faculty will continue to increase, assuming that women stay in academic positions at a rate equal to or greater than men.

Underrepresented Minorities

The U.S. Census Bureau's demographic projections have long indicated an increasing prominence of minority groups among future college and working-age populations. With the exception of Asians/Pacific Islanders, these groups have tended to be less likely than the majority population to earn S&E degrees or work in S&E occupations. Private and gov-

Figure 5-25.
Growth in full-time doctoral S&E faculty, by rank and sex: 1973–99



NOTE: Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

ernmental groups have sought to broaden the participation of blacks, Hispanics, and American Indians/Alaskan Natives in these financially attractive fields, with many programs targeting their advanced training through the doctorate.

In response, the rate of increase in conferrals of Ph.D.s to members of minority groups has been steep,[27] as have increases in academic employment; but taken together, blacks, Hispanics, and American Indians/Alaskan Natives remain a small minority. (See figure 5-26 and appendix table 5-31.) Because the increases in hiring come from a very small base, these groups still constitute less than 7 percent of total employment but represent nearly 10 percent of recent Ph.D.-holders hired into academia. Their share of full-time faculty positions is very similar to their employment share. Compared with whites, blacks tend to be relatively concentrated in the social sciences and psychology and relatively less so in the physical, environmental (earth, atmospheric, and ocean), and life sciences. The field distribution of Hispanic degree-holders is similar to that of the majority.

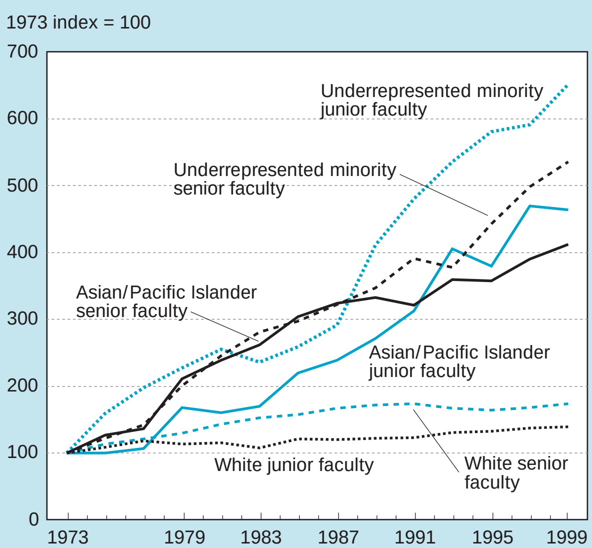
Asians/Pacific Islanders

Asians/Pacific Islanders as a group have been quite successful in entering the academic doctoral workforce in S&E, sending their employment share from 4 to 11 percent since 1973. Compared with whites, they are more heavily represented in engineering; represented to lesser degrees in life and physical sciences, mathematics, and computer science; and represented at very low levels in psychology and social sciences. In 1999, Asians/Pacific Islanders constituted nearly one-quarter of academic doctoral computer scientists and 18 percent of engineers. (See appendix table 5-31.)

In the last half of the 1990s, the percentage of Asian Ph.D.s among recent doctorate-holders sharply reversed a steep two-decade climb. The decline reflects a sharp drop in the percentage of all S&E doctoral degrees earned by Asians in the closing years of the 1990s. Between 1995 and 1999, S&E doctoral degrees awarded in the United States fell by 2 percent, but those awarded to Asians dropped by 45 percent. Consequently, the share decline of Asians among recent doctorate-holders is also evident in industry and other employment sectors.

[27]This, in turn, reflects their rising participation in higher education and graduate school training. See "Master's Degrees by Sex, Race/Ethnicity, and Citizenship" and "Doctoral Degrees by Race/Ethnicity" in chapter 2.

Figure 5-26.
Growth in full-time doctoral S&E faculty, by rank and race/ethnicity: 1973–99



NOTES: Underrepresented minority faculty includes blacks, Hispanics, and American Indians/Alaskan Natives. Junior faculty includes assistant professors and instructors; senior faculty includes full and associate professors.

See appendix table 5-31. *Science & Engineering Indicators – 2002*

Size of the Academic Research Workforce

The intertwined nature of research, teaching, and public service in academia makes it difficult to define the size of the academic research workforce precisely. Therefore, two estimates of the number of academic researchers are presented: a headcount of those who report that research is their primary work activity, and a headcount of those who report that research is either their primary or secondary work activity.

Postdocs and those in nonfaculty positions are included in both estimates. To provide a more complete measure of the number of researchers, a lower-bound estimate of the number of graduate students who support the academic research enterprise is included, based on those with research assistantship (RA) support.

Research as Primary Work Activity

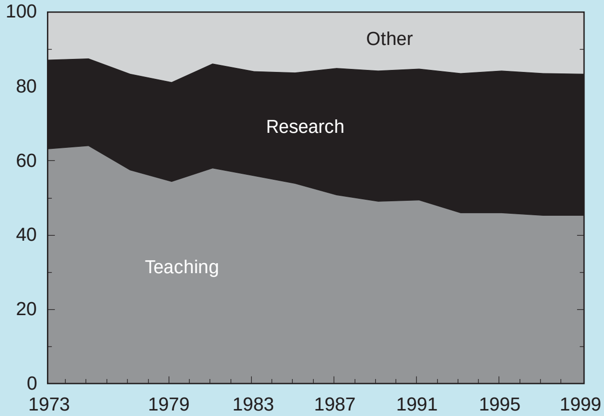
By this measure, the growth of doctoral-level academic researchers has been substantial, from 27,800 in 1973 to 91,400 in 1999. (See appendix table 5-32.) During this period, the number of those with teaching as their primary activity increased much less rapidly, from 73,300 to 108,600. Figure 5-27 displays the resulting shifting proportions in the academic workforce. It shows that after many years of increase, the proportion of those reporting research as their primary activity leveled off in the 1990s, as did the steep drop in those reporting teaching as their primary activity.

The different fields have distinct patterns of relative emphasis on research, but the shapes of their overall trends are largely the same. Life sciences, however, stand out for their much higher proportion of those identifying research as their primary activity and, correspondingly, their much lower proportion of those reporting teaching as their primary activity. (See figure 5-28.)

Research as Either Primary or Secondary Work Activity

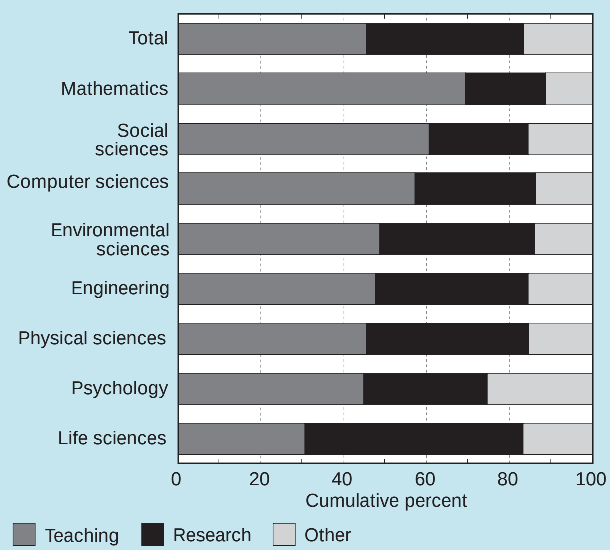
This measure, a straightforward headcount of doctoral respondents for whom research is either the primary or secondary work activity, also shows greater growth in the research than in the

Figure 5-27.
Primary work activity of academic doctoral S&E faculty: 1973–99



See appendix table 5-32. *Science & Engineering Indicators – 2002*

Figure 5-28.
Primary work activity of academic doctoral S&E workforce: 1999



See appendix table 5-32. *Science & Engineering Indicators – 2002*

teaching component. The number of doctoral researchers so defined increased from 82,300 in 1973 to 168,100 in 1999, that of teachers from 94,900 to 158,700.[28] (See appendix table 5-33.)

Life sciences accounted for much of this trend, with researchers growing from 26,000 to 60,800 and teachers from about the same base of 25,300 to 43,600. The other fields generally included fewer researchers than teachers in the early 1970s, but this trend has been reversed for physical, earth, atmospheric, and ocean sciences and engineering.

The close coupling of advanced training with hands-on research experience is a key strength of American graduate education. To the headcount of doctoral researchers for whom research is a primary or secondary work activity must thus be added an estimate of the number of graduate students who are active in research. The more than 300,000 full-time S&E graduate students can be expected to contribute significantly to the conduct of academic research.

Graduate RAs were the primary means of support for slightly more than one-quarter of these students. Text table 5-8, which shows the distribution of all full-time graduate students and graduate research assistants by field over the past quarter century, indicates that the number of research assistants has grown faster than overall graduate enrollment. In both enrollment and distribution of RAs, a shift away from physical sciences and into life sciences has occurred. Nevertheless, engineering, natural sciences, and mathematics and computer sciences have relatively higher proportions of research assistants measured against their enrollment.[29] For life sciences, enrollment and research assistant proportions are in balance, reflecting the relatively heavier reliance of these fields on postdoctoral researchers.

In estimating the headcount of doctoral researchers for whom research is the primary or secondary activity, only graduate research assistants (full-time graduate students whose primary mechanism of support is an RA) are included. Thus, the estimate excludes graduate students who rely on fellowships, traineeships, or teaching assistantships for their support, as well as the nearly 40 percent who are primarily self-supporting; and foreign-degreed doctoral researchers. With these caveats, the number of academic researchers in 1999 for whom research is the primary or secondary activity is estimated to have been close to 260,000. (See figure 5-29 and appendix table 5-34.) It is worth noting that in computer science and engineering the number of graduate research assistants exceeded the number of doctoral researchers.

Deployment of the Academic Research Workforce

This section describes trends in researcher headcount and in the number of S&E academicians whose primary activity is research. They are discussed as measures of the relative research intensity of academic institutions and the distribution of the academic research workforce across types of institutions, positions, and fields. The analysis is based on doctoral scientists and engineers with degrees from U.S. institutions, because insufficient detail is available for those with foreign degrees.

Distribution Across Types of Academic Institutions

The majority of the research workforce is concentrated in the research universities, followed by comprehensive and doctorate-granting institutions and freestanding medical institutions. (See appendix table 5-35.) In 1999, the research

[28]This measure was constructed slightly differently in the 1980s and in the 1990s, starting in 1993, and is not strictly comparable across these periods. Therefore, the crossing over of the two trends in the 1990s could reflect only a methodological difference. However, the very robust trend in the life sciences, where researchers started outnumbering teachers at a much earlier time, suggests that this methodological artifact cannot fully explain the observed trend.

[29] This reflects increasing support for computer science R&D.

Text table 5-8.
Full-time S&E graduate students and graduate research assistants at U.S. universities and colleges, by field

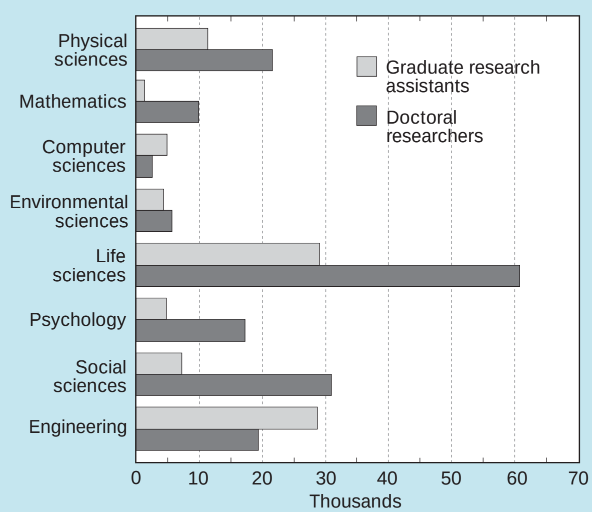
Year	Total S&E	Engineering	Physical sciences	Environmental sciences[a]	Mathematics and computer sciences	Life sciences	Psychology	Social sciences
Full-time graduate students (thousands)								
1973	161.6	31.2	21.1	7.8	13.3	40.7	15.2	32.4
1983	252.1	53.9	25.2	12.0	21.6	69.3	26.6	43.5
1993	329.7	73.8	30.6	11.4	31.9	91.7	34.8	55.6
1999	334.4	67.8	26.6	10.5	34.5	107.0	34.7	53.3
Full-time graduate research assistants (thousands)								
1973	35.9	10.4	6.3	2.6	1.4	9.5	1.9	4.0
1983	54.9	15.5	9.1	3.5	2.2	16.5	3.0	5.0
1993	90.2	27.9	12.3	4.7	5.2	28.0	4.6	7.4
1999	91.3	28.7	11.3	4.3	6.2	29.0	4.8	7.2
Distribution of full-time graduate students (percent)								
1973	100	19	13	5	8	25	9	20
1983	100	21	10	5	9	27	11	17
1993	100	22	9	3	10	28	11	17
1999	100	20	8	3	10	32	10	16
Distribution of full-time graduate research assistants (percent)								
1973	100	29	18	7	4	26	5	11
1983	100	28	17	6	4	30	5	9
1993	100	31	14	5	6	31	5	8
1999	100	31	12	5	7	32	5	8

[a]Environmental sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Graduate Students and Postdoctorates.

Science & Engineering Indicators – 2002

Figure 5-29.
Estimated number of doctoral academic researchers and graduate research assistants, by field: 1999



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

See appendix table 5-34. *Science & Engineering Indicators – 2002*

universities employed 54 percent of doctoral scientists and engineers in academic positions, 61 percent of academic researchers (headcount), 76 percent of those whose primary activity is research, and 80 percent of graduate research assistants. The employment shares of the other institutions are generally the same or higher than their share of the researcher measures.

Over the years, the research universities' share of academic researchers has declined, reflecting their decreasing shares of total and Federal academic research expenditures. The research universities' losses were offset by gains in several other types of institutions. Text table 5-9 provides a long-term overview of the changes in these institutional distributions. (See appendix table 5-35.)

Distribution Across Academic Positions

A pool of academic researchers outside the regular faculty ranks has grown over the years, as shown by the distribution of the doctoral research workforce across different types of academic positions: faculty, postdoctoral fellows, and all other types of appointments. (See text table 5-10 and appendix table 5-36.) The faculty share of the academic research workforce (77 percent in 1999, approximately the same as their employment share) represents a decline from 89 percent in 1973. The shift toward nonfaculty research effort was

Text table 5-9.
Distribution of academic doctoral employment and researchers, by institution type
(Percentage)

Type of institution	Employment		Researchers		Graduate Research Assistants	
	1970s	1990s	1970s	1990s	1970s	1990s
Total	100.0	100.0	100.0	100.0	100.0	100.0
Research universities	57.3	54.6	66.7	61.4	87.8	81.2
Doctorate-granting institutions	12.3	12.2	11.6	12.1	9.1	11.2
Comprehensive institutions	18.6	19.4	12.7	15.0	1.7	4.5
All others	11.8	13.8	9.0	11.5	1.2	3.1

NOTES: Researchers are headcounts of those with research as primary or secondary work activity. “All others” includes freestanding medical schools, schools of engineering, and four-year colleges.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-10.
Change in the composition of academic employment and academic researchers

Year	Total employment	Researcher headcount	Research is primary activity
Number (thousands)			
1973	118.0	82.3	27.8
1983	176.1	104.7	48.9
1993	213.8	150.1	80.2
1999	240.2	168.1	91.4
Full-time faculty (%)			
1973	87.6	87.5	71.3
1983	84.3	83.0	68.8
1993	80.7	81.1	70.9
1999	76.6	76.8	66.1
Postdoctorates (%)			
1973	3.5	4.9	13.8
1983	4.7	7.1	14.6
1993	6.2	8.9	15.8
1999	7.7	10.6	18.2
Other full- and part-time positions (%)			
1973	6.4	5.6	11.3
1983	9.2	8.6	14.4
1993	13.1	10.0	13.3
1999	15.6	12.5	15.7

NOTE: Researcher headcount is the sum of those for whom research is either the primary or secondary work activity.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix table 5-36. *Science & Engineering Indicators – 2002*

especially pronounced in the 1990s. The data on share of employment and researcher headcount show increases for both postdoctorates and those in a variety of nonfaculty positions.

Distribution Across S&E Fields

The distributions of researchers and those whose primary activity is research were compared with the employment distribution. Researcher proportions in excess of a field’s employment share were deemed to indicate greater research intensity. Text table 5-11 suggests that, by these measures, life sciences expend relatively more research effort than the other fields, and mathematics and social sciences expend relatively less. Life sciences have a smaller-than-expected share of graduate research assistants, reflecting their relatively heavy use of postdoctorates in research. (See appendix table 5-37.)

Research Intensity of Academic Institutions

Has the relative importance given to R&D in U.S. universities and colleges changed? In terms of inputs, this question has already been addressed by examining the number of dollars spent on R&D. See “Emphasis on Research at Universities and Colleges” earlier in this chapter. In this section, the question is addressed in terms of the number of academic research personnel using relative-to-total doctoral employment in S&E. The two measures, headcount and the number of those reporting research as their primary work activity, tell somewhat different stories. The reader is cautioned that the resulting ratios are suggestive rather than definitive.

The number of researchers (headcount) relative to total employment declined from its high in the 1970s to a low in the mid-1980s, then rose again to about the previous levels, indicating declining research intensity during the 1970s and early 1980s, when R&D funds grew relatively slowly. (See text table 5-12 and appendix tables 5-35 to 5-37.) The data also show that for computer sciences and earth, atmospheric, and ocean sciences, levels of research involvement were somewhat lower in the late 1990s than earlier in the decade. A long-term upward trend, from about 25 percent of total employment to nearly 40 percent, is evident in the percentage of those whose primary activity is research. This may indicate a strengthening of the research function in academia. (See figure 5-30.)

Text table 5-11.
Distribution of academic employment and researchers, by field: 1999
(Percent of academic total)

Field	Total employment	Researcher headcount	Research is primary activity	Graduate research assistants
Total	100.0	100.0	100.0	100.0
Physical sciences	12.9	12.8	13.3	12.3
Mathematics	6.3	5.9	3.2	1.4
Computer sciences	1.5	1.6	1.2	5.4
Earth, atmospheric, and space sciences	3.2	3.4	3.2	4.7
Life sciences	34.1	36.2	47.2	31.7
Psychology	12.1	10.2	9.5	5.3
Social sciences	19.2	18.4	12.1	7.9
Engineering	10.6	11.6	10.3	31.4

NOTES: Percentages may not add to 100 because of rounding. Researcher headcount is the sum of those for whom research is either the primary or secondary work activity.

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-12.
Research intensity of American universities
(Ratio of researcher headcounts to employment)

Field	1973	1983	1993	1999
S&E total	0.70	0.59	0.70	0.70
Physical sciences	0.74	0.64	0.70	0.70
Mathematics	0.70	0.56	0.62	0.65
Computer sciences	NA	0.74	0.79	0.71
Earth, atmospheric, and ocean sciences	0.72	0.68	0.78	0.73
Life sciences	0.75	0.70	0.76	0.74
Psychology	0.60	0.50	0.60	0.59
Social sciences	0.61	0.46	0.66	0.67
Engineering	0.73	0.62	0.76	0.76

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix tables 5-35 to 5-37.

Science & Engineering Indicators – 2002

Government Support of Academic Doctoral Researchers

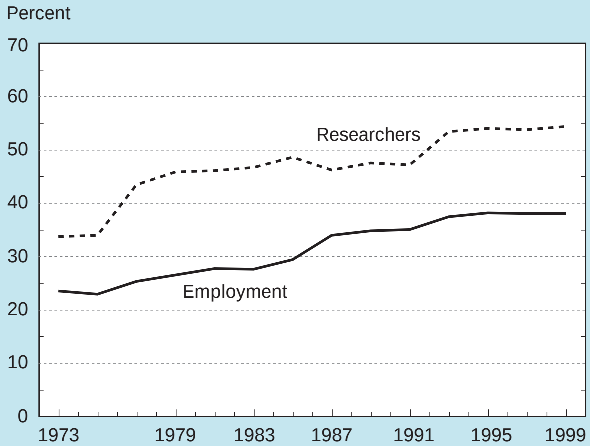
Academic researchers rely on the Federal Government for a significant share of their overall research support because about 60 percent of all academic R&D is federally funded. The institutional and field distributions of these funds are well documented, but little is known about their distribution across researchers. This section presents data from reports by doctoral scientists and engineers about the presence or absence of Federal support and an indication from those so supported as to which agencies have provided them with funds. However, nothing is known about the magnitude of these funds to individual researchers. (See sidebar, “Interpreting the Federal Support Data.”)

Appendix table 5-38 shows the percentage of academic doctoral scientists and engineers who have received Federal support for their work, broken out by field. The analysis examines the overall pool of doctoral S&E researchers as well as young Ph.D.-holders, for whom support may be especially critical in establishing a productive research career.

Academic Scientists and Engineers With Federal Research Funds

In 1999, the Federal Government supported an estimated 46 percent of all doctoral academic scientists and engineers, 74 percent of those for whom research was the primary responsibility, and 37 percent of those for whom research was a secondary responsibility. (See appendix table 5-38.) With the exception of engineering, no major shifts appear to have occurred in the overall percentage of those so supported during the 1993–97 period. However, as text table 5-13 shows, the 1999 percentages, for S&E as a whole and physical sciences, mathematics, life sciences, psychology, and social sciences, were below those of the late 1980s, when Federal academic research funds were growing rapidly.

Figure 5-30.
S&E Ph.D.s employed in academe with research as primary activity as a percentage of all academic S&E Ph.D.s and of academic S&E Ph.D. researchers: 1973–99



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

See appendix tables 5-32 and 5-34.

Science & Engineering Indicators – 2002

The percentage of researchers who receive Federal support differs greatly across the S&E fields. In 1999, Federal support of S&E researchers ranged from 63 percent in earth, atmospheric, and ocean sciences to 29 percent in mathematics and 23 percent in social sciences. The earlier series (1973–91) shows an overall decline in the proportion of federally supported researchers through the early 1980s that coincided with stagnant real Federal R&D funds to academia, followed by a rise in the proportion supported during the second half of the 1980s, when funding again rose robustly. (See appendix table 5-38.)

Full-time faculty received Federal funding less frequently than other full-time doctoral employees, who, in turn, were less frequently supported than postdoctorates. In 1999, 43 percent of full-time faculty, 50 percent of other full-time employees, and 80 percent of postdoctorates received Federal support. Again, these proportions were lower than those during the latter part of the 1980s. (See appendix table 5-38.) It is unclear whether these estimates indicate relatively less generous support or greater availability of funds from other sources, some of which may not flow through university accounts.

Interpreting Federal Support Data

Interpretation of the data on Federal support of academic researchers faces a technical difficulty. Between 1993 and 1997, respondents to the *Survey of Doctorate Recipients* were asked whether work performed during the week of April 15 was supported by the Federal Government; in most other survey years, the reference was to the entire preceding year; in 1985, it was to one month. However, as clearly illustrated by these data series, the volume of academic research activity is not uniform over the entire academic year. A one-week (or one-month) reference period seriously understates the number supported over an entire year. Thus, the 1993–97 numbers (and those for 1985) cannot be compared directly with results for the earlier years or those from the 1999 survey, which again used an entire reference year.

The discussion here compares 1999 data with the earlier series and examines trend information for the mid-1990s using the 1993–97 data points. All calculations express the proportion of those with Federal support relative to the number responding to this question. The reader is cautioned that, given the nature of these data, the trends discussed are broadly suggestive rather than definitive. The reader also is reminded that the trends in the proportion of all academic researchers supported by Federal funds occurred against a background of rising overall numbers of academic researchers.

Federal Support of Young Academic Ph.D.-Holders

Early receipt of Federal support is viewed as critical to launching a promising academic research career. The Federal

Text table 5-13.
Percentage of academic doctoral scientists and engineers with Federal support

Field	1979	1989	1999
S&E total	39.9	49.4	46.1
Physical sciences	44.1	58.2	55.7
Mathematics	21.7	33.5	29.1
Computer sciences	34.8	52.4	55.6
Earth, atmospheric, and ocean sciences	45.4	63.8	63.3
Life sciences	55.3	65.1	57.9
Psychology	32.6	35.5	32.9
Social sciences	20.4	27.7	22.9
Engineering	49.1	56.3	56.9

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Government supports young academic doctoral scientists and engineers at higher rates than it does the overall academic S&E workforce but supports those in full-time faculty positions, as opposed to postdocs and those in other full-time positions, at lower rates. (See appendix tables 5-38 and 5-39.) Overall, 53 percent of those with recently earned doctorates (within three years of the survey) received Federal research funds, but only 29 percent of those in full-time faculty positions did (sharply lower than the rate of nearly 40 percent in the late 1980s). On the other hand, 80 percent of the postdocs had Federal funds. Mathematics and psychology stood out as having low percentages of postdocs with Federal support (59 and 64 percent, respectively) compared with 77 to 82 percent for the other fields.

In 1999, after young academics had gained some experience (i.e., four to seven years after award of the doctorate) their proportions of Federal support looked similar to those of the workforce as a whole. However, except for psychology, they experienced a much sharper decline in Federal support between 1989 and 1999. (See appendix tables 5-38 and 5-39 and text table 5-14.)

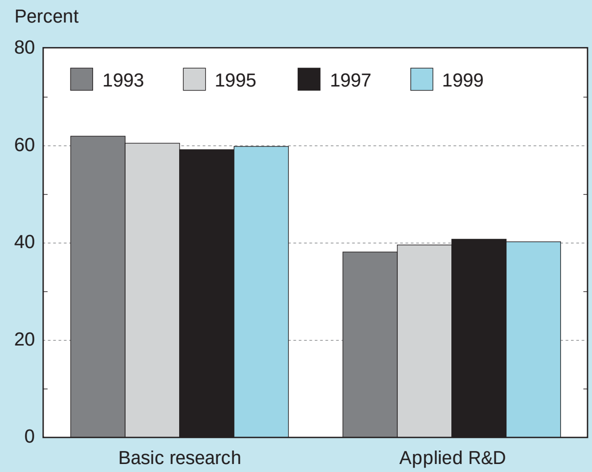
Has Academic R&D Shifted Toward More Applied Work?

Emphasis on exploiting the intellectual property that results from the conduct of academic research is growing. See "Outputs of Scientific and Engineering Research: Articles and Patents." Among the criticisms raised against this development is that it distorts the nature of academic research by focusing it away from unfettered basic research and toward the pursuit of more utilitarian, problem-oriented questions. One aspect of this issue is addressed in this section.

Did a shift toward applied research, design, and development occur during the 1990s, a period when academic patenting and licensing activities grew steeply? Doctoral academic scientists and engineers were asked about their primary or secondary work activities, including four R&D functions: basic research, applied research, design, and development. These data are used to address the question posed here.

As figure 5-31 shows, a very modest shift away from basic research from 61.9 percent in 1993 to 59.9 in 1999, which barely reaches statistical significance, is evident among those listing research as their primary work activity. However, when the headcount of all researchers is considered, no such effect is seen. These data suggest that among those whose primary work activity is research, some modest shift toward more applied work may have occurred. They also suggest that most academic researchers do not perceive a shift toward more applied kinds of research functions.

Figure 5-31.
Distribution of academic researchers' activities, by research function



NOTE: Academic researchers include those whose primary or secondary work activity is basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics. Survey of Doctorate Recipients.

Science & Engineering Indicators – 2002

Text table 5-14.
Percentage of academic doctoral scientists and engineers four to seven years after receiving their Ph.D. who have Federal support

Field	1979	1989	1999
S&E total	43.0	57.8	47.4
Physical sciences	52.0	72.4	57.0
Mathematics	32.3	39.0	32.2
Computer sciences	—	70.8	56.6
Earth, atmospheric, and ocean sciences	49.6	81.2	65.3
Life sciences	57.3	71.9	57.2
Psychology	39.3	36.1	35.6
Social sciences	20.8	33.2	22.8
Engineering	55.1	70.8	55.5

— = estimate suppressed because of small sample size

SOURCE: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients.

See appendix tables 5-38 and 5-39.

Science & Engineering Indicators – 2002

Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed in chapter 4 of this volume and earlier in this chapter. This section presents two sets of indicators of advances in knowledge: articles published in a set of the world's most influential refereed journals (see sidebar, "Data Sources for Article Outputs") and patents awarded to U.S. universities and colleges.

Although academic researchers contribute the bulk of all scientific and technical articles published in the United States, the focus in this section is considerably broader. It includes U.S. articles in all sectors and total U.S. articles in the context of article outputs of the world's nations. The output volume of research, or article counts, is one basic indicator of the degree to which different performers contribute to the world's production of research-based S&E knowledge. The outputs of different U.S. sectors (universities and colleges, industry, government, and nonprofit institutions) indicate the relative prominence of these organizations in the United States overall and in particular S&E fields. The same indicator, aggregated by country, provides approximate information about the U.S. position in the global S&E enterprise and the emergence of centers of S&E activity to stimulate it, especially during the past decade.

Scientific collaboration in all fields increasingly crosses organizational and national boundaries. Articles by multiple authors in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen as governments have acted to stimulate it, especially over the past decade. Cross-sectoral collaboration is viewed as a vehicle for moving research results toward practical application. International collaboration, often compelled by reasons of the cost or scope of the issue, provides intellectual cross-fertilization and ready access to work done elsewhere.

The perceived influence of research results to advance the state of knowledge is reflected in citations. Both domestic and international citation patterns are examined in this section. References to scientific and technical articles on patents, which suggest the relatedness of research to presumed practical application, are also examined.

Finally, patents issued to U.S. universities are discussed. They provide another indicator of the perceived utility of the underlying research, with trends in their volume and nature

Data Sources for Article Outputs

The article counts, coauthorship data, and citations discussed in this section are based on S&E articles published in a stable set of about 5,000 of the world's most influential scientific and technical journals tracked since 1985 by the Institute of Scientific Information's (ISI's) Science Citation Index (SCI) and Social Science Citation Index (SSCI). Fields in these databases are determined by the classification of the journals in which articles appear. Journals, in turn, are classified based on the patterns of their citations. (See text table 5-15.)

Text table 5-15.
Classification of Institute for Scientific Information (ISI)-covered journals

Field	Percent of Journals
Clinical medicine	24
Biomedical research	11
Biology	10
Chemistry	7
Physics	5
Earth and space sciences	5
Engineering and technology	8
Mathematics	3
Psychology	6
Social sciences	11
Professional and health sciences[a]	10

[a]These fields have citation patterns strongly linked to social sciences and/or psychology. Appendix table 5-40 lists the constituent subfields (fine fields) of the journals covered here.

See appendix table 5-40. *Science & Engineering Indicators – 2002*

SCI and SSCI appear to give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias. Journals of regional or local importance are not necessarily well covered, which may be salient for the categories of engineering and technology, psychology, social sciences, health, and professional fields, as well as for nations with a small or applied science base.

Articles are attributed to countries and sectors by the author's institutional affiliation at time of authorship. Thus, "coauthorship" or "multiauthorship" here refers to institutional coauthorship; a paper is considered coauthored only if its authors have different institutional affiliations. The same applies to cross-sectoral or international collaborations. For example, a paper written by an American temporarily residing in Britain with someone at his or her U.S. home institution is counted as internationally coauthored, thus overstating the extent of such collaborations. Likewise, an article written by a British citizen temporarily located at a U.S. university with a U.S. colleague would not be counted as internationally coauthored, thus understating the count. All data presented here derive from the Science Indicators database prepared for NSF by CHI Research, Inc. The database excludes all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

indicating the universities' interest in seeking commercialization of its results.

Publication Counts: U.S. and Worldwide Trends

The volume of articles published in the world's key science and technology (S&T) journals is an indicator of the national output of scientific and technical research in the United States and other countries. These core journals exercise a degree of quality control by requiring articles submitted for publication to undergo peer review, which in turn allows comparison of countries' relative efforts and helps reveal their priorities for scientific research. It also permits insight into both the patterns of collaboration across institutions and national borders and the degree and type of knowledge cited in scientific and technical articles.[30]

On a worldwide basis, scientific articles increased by 14 percent between 1986 and 1999, an average of 1 percent growth per year.[31] By region, the growth trend was disparate, with only the Pacific and Near East registering gains near the worldwide trend. Much of the growth was due to an increase of more than 30 percent in Western Europe, primarily in countries that are members of the Organization of Economic Cooperation and Development (OECD). These OECD countries account for more than 95 percent of Western Europe's output. It is likely that these gains reflect, at least in part, these nations' individual efforts as well as those of the European Union (EU) and other regional programs to strengthen the science base.[32] Many of the smaller and/or newer members of the EU, such as Austria, Belgium, Finland, Greece, Ireland, Portugal, and Spain, had very strong gains during this period. (See figure 5-32 and appendix table 5-41.)

Another region that witnessed very strong gains was Asia, where output nearly doubled during this period, primarily in the eastern half of Asia. This jump in output was driven by Japan, newly industrialized economies (NIEs) (South Korea, Taiwan, Singapore, and Hong Kong), and China. Despite its economic difficulties, Japan's output of articles grew by nearly 50 percent, coinciding with an increase in its R&D expenditures. The collective output of NIEs rose more than sevenfold during this period, coinciding with their rapid economic, technological, and scientific progress. China, a country with a far lower per capita income level compared with NIEs, registered a threefold gain in its publication output. China's economic development has characteristics similar to those of NIEs, as it has rapidly industrialized, adopted economic reform, and increased its expenditures for R&D. In the western half of Asia, output fell during this period by 5 percent due to a 7 percent decrease in India's output, a matter of concern to that nation (see Raghuram and Madhavi 1996).[33]

The largest increase in any region during this period occurred in Latin America, which more than doubled its output. However, this increase was from a low base and concentrated in three countries (Argentina, Brazil, and Mexico), which generated nearly 80 percent of the articles produced by this region in 1999. These countries share the following characteristics: a moderately high per capita income, a relatively large pool of scientists and engineers, and recent reform of their economies and scientific enterprise. In addition, Brazil and Mexico raised expenditures for R&D during the early and mid-1990s.[34]

The Near East, comprising North Africa and the Middle Eastern countries, increased its output by 20 percent during this period. Although Israel, a mature and wealthy industrialized country, dominates output in this region, its growth was stagnant. Excluding Israel, output rose by more than 50 percent during this period. Countries in North Africa, such as Algeria, Morocco, and Tunisia, and in the Middle East, such as Iran, Jordan, and Syria, more than doubled their output of journal articles, although this increase was from a very low base.

Regions whose share of world output decreased were Eastern Europe, Sub-Saharan Africa, and North America. (See

[30] To facilitate comparisons between countries, the numbers reported here are based on the 1985 ISI set of core journals. This set of influential world S&T journals has some English language bias but is widely used around the world. See, for example, Organization of American States (1997) and European Commission (1997). Also see the sidebar, "Data Sources for Article Outputs" in this chapter.

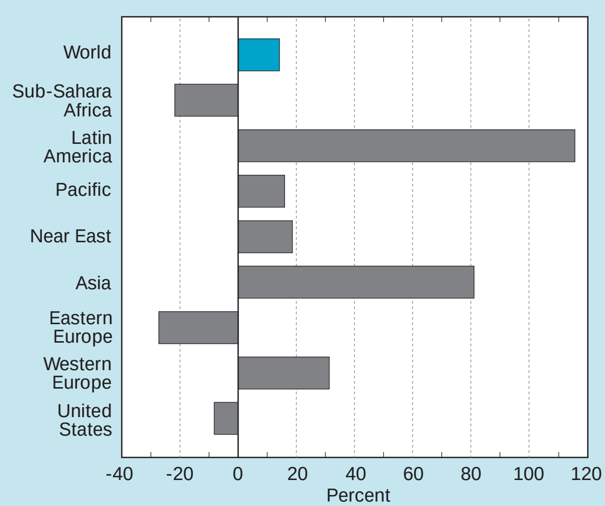
[31] This is a minimum estimate. An expanded 1991 journal set yields an average per annum growth rate of 1.4 percent for the 1990s. In addition, a fixed journal set is biased against growth by excluding the addition of new journals.

[32] These include five-year Framework Programmes of the EU, EU funding provided through Structural Funds, Community Initiatives Programmes, and efforts outside the EU framework such as EUREKA, a program to stimulate partnerships between industry, universities, and research institutes. See NSF (1996) for a brief discussion and European Commission (1997) for a fuller treatment.

[33] The authors note that this decline cannot be attributed to journal coverage in the SCI and that it is paralleled by a decline in citations to articles by authors from India. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young scientists from India whose articles would be counted in the countries in which they reside, not in their country of origin.

[34] See the NSF report, "Latin America: R&D Spending Jumps in Brazil, Mexico, and Costa Rica at <http://www.nsf.gov/sbe/srs/nsf00316/start.htm>.

Figure 5-32.
Growth trends in scientific and technical publications by region: 1986–99

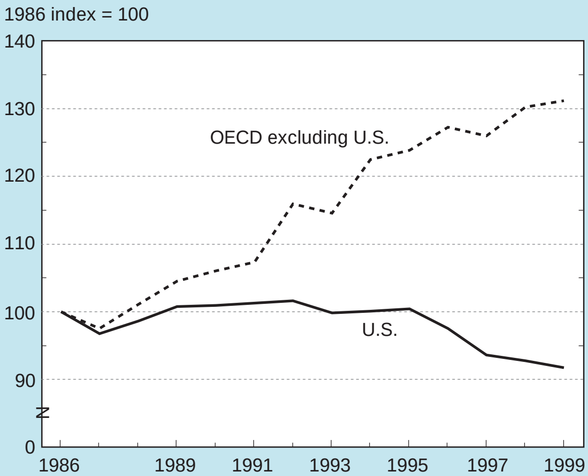


See appendix table 5-41. *Science & Engineering Indicators – 2002*

Trends in U.S. Scientific and Technical Articles

The number of scientific and technical articles by United States authors appears to have peaked in 1992, then fallen throughout the remainder of the 1990s, with output in 1999 down by 10 percent compared to 1992. This trend diverged from growth in most other OECD countries during this period and is a reversal from three prior decades of consistent growth. (See figure 5-33.)

Figure 5-33.
Output of scientific and technical papers for the U.S. and OECD: 1986–99



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

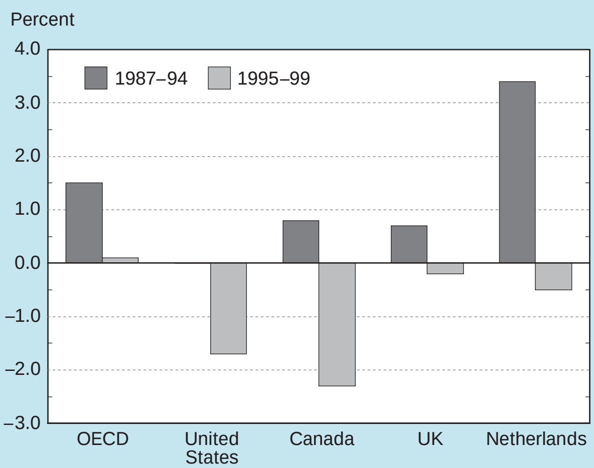
See appendix table 5-41. *Science & Engineering Indicators – 2002*

The 1985 journal set on which much of this chapter's analysis is based is biased against growth because it excludes articles published in journals issued since 1985. However, a larger set of journals from 1991 and 1995 shows similar trends for U.S. scientific and technical articles through the latter half of the 1990s. The reasons for this development remain unknown.

This phenomenon is not limited to the United States. Three industrialized countries with a significant output of publications (Canada, the United Kingdom, and the Netherlands) also experienced a fall in S&T articles during the latter half of the 1990s. (See figure 5-34.) In addition, in the latter half of the 1990s, the growth rate in the output of most other OECD countries slowed relative to the early 1990s.

As shown in text table 5-16, the downward trend in U.S. scientific and technical articles has been broad based, affecting almost all fields:

Figure 5-34.
Average growth in scientific and technical papers for selected countries



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

See appendix table 5-41. *Science & Engineering Indicators – 2002*

Text table 5-16.
Change in U.S. output of scientific and technical articles, by fields: 1992–1999

Field	1992–1999 (percent change)	Percentage contribution to total decline
All fields/total	–10	100
Life sciences	–7	41
Clinical medicine	–5	15
Biomedical research	–6	10
Biology	–22	16
Chemistry	–9	7
Physics	–9	9
Earth and space sciences	13	–6
Engineering and technology	–26	19
Mathematics	–10	2
Social and behavioral sciences	–19	28

NOTE: Social and behavioral category consists of the social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

- The largest decrease in published articles, 26 percent, occurred in the engineering and technical field, which accounted for 19 percent of the overall decline.
- Life sciences accounted for more than 40 percent of the overall decrease in articles. Biology experienced the steepest decrease (22 percent), accounting for 16 percent of the overall decline. Although the decrease in articles in clinical medicine and biomedical research was much smaller (5 and 6 percent, respectively), these two fields accounted for 25 percent of the overall decline due to their preponderant share (49 percent) of scientific and technical articles.
- Output in social sciences and related fields fell 19 percent, accounting for almost one-third of the overall decline.
- Articles in chemistry and physics each decreased by 9 percent during this period, accounting for 16 percent of the overall decline.

Almost all sectors were affected by this trend in S&T articles. Together, the private for-profit sector, which experienced a 24 percent decrease, and the Federal Government, which experienced a 17 percent decrease, accounted for 35 percent of the overall decline. (See text table 5-17.) The decrease in articles produced within academia was less pronounced (9 percent) but, because of the sector's high share of total output, it accounted for 64 percent of the overall decline.

In each of these sectors, several fields were most affected. In academia, almost half of the decrease was in the life sciences; one-third was in the social sciences; and about 15 percent was in the engineering and technical field. The life sciences were also the prime factor in the fall in publications in the Federal Government, accounting for two-thirds of the overall decrease. The engineering and technical field and social sciences contributed to most of the remainder of the lower article output in this sector. In the private sector, more than 80 percent of the decline was in three fields: physics (38 percent), engineering and technical (24 percent), and chemistry (19 percent).

A preliminary review of the reasons behind the trends in the number of U.S. articles examined the following:

- **Methodology.** Article counts for the United States and other countries are based on a fixed set of journals from the 1985 SCI/SSCI database. Unless noted, the journals are counted on a fractional basis, which credits the authors of multiple authored papers their fractional contribution. Although this approach facilitates consistent comparison over time and between countries, it biases against growth, for two reasons: A fixed set of journals excludes new journals that have been added to the SCI/SSCI database. Growth in international collaboration depresses the count of each nation's internationally coauthored papers (because each country's coauthor is credited with a portion of the paper). If counting is done on the basis of the entire SCI/SSCI database and with whole counts, the number of U.S. articles shows growth; however, their growth rate is slowing.
- **Coverage.** The coverage of the SCI/SSCI database may be incomplete or otherwise flawed, a problem shared by all bibliographic databases because of the impossibility of indexing all scientific literature. The SCI/SSCI database, however, has the most complete coverage of any bibliographic database, and it arguably covers the most significant and important peer-reviewed scientific journals. Because only a fraction of scientific literature is considered to be of high quality and important, based on the frequency of citations, the limited coverage of bibliographic databases does not appear to be a major problem for measuring quality scientific publications.
- **Electronic publishing.** The Internet is changing scholarly communication, but whether it is depressing traditional publishing is unclear. The number of peer-reviewed electronic publications has grown rapidly, from 29 in 1993 to 1,049 in 1997.* Although high-quality electronic journals are included in the SCI/SSCI database, it is possible that some publications are missed, especially if these journals are rapidly expanding. One way to ascertain whether electronic publishing is implicated in the U.S. article decline is to see whether established journals are citing electronic journals. An analysis of reference patterns in a sample of 986 papers published in 1990, 1995, and 1997 found few references to Internet URLs. The lack of references

Text table 5-17.
Trend in U.S. scientific and technical articles, by sector: 1992–99
(Percentage)

Sector	Decline	Contribution
Total	10	100
Academia	9	64
Federal Government	17	14
Private	13	20
For profit	24	21
Nonprofit	1	1
FFRDC	1	0
Other	13	3

FFRDC = Federally Funded Research and Development Center

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

* National Science Board. 2000. *Scientific and Engineering Indicators 2000.* NSB-00-1. Arlington, VA: National Science Foundation, pp. 9–30.

to Internet URLs might indicate that this practice was not very common in 1997.

- **Commercialization of academic science.** Academic science may have become increasingly commercialized over the past two decades. Universities, often in partnership with industry, have moved to commercialize their research through patenting, licensing, and establishing spin-off companies. In this environment, some academic researchers may be delaying or withholding their research because of proprietary concerns. In addition, patenting by academic researchers might absorb time that would otherwise be devoted to publishing. Some research suggests that researchers in the life sciences, which has been the key field in commercialization, delay or refrain from publishing. A 1997 survey of life science researchers found that 30 percent of respondents reported that they delayed or withheld publication of their research due to proprietary concerns.[†] In addition, in a survey of 1,000 technology managers and faculty of top research universities, 79 percent of technology managers and 53 percent of faculty reported that participating firms had asked that certain research findings be delayed or withheld from publication.[‡] Although the number of articles in this field fell at a slower rate than that of the overall decline, this field's predominance meant that it accounted for almost half of the apparent decrease. By sector, it was the major factor in the decline in articles from universities and the Federal Government. However, there appears to be no significant difference in the overall output of articles from universities that are major patenters and those that are not. The change in output of the former between the two three-year periods ending in 1995 and 1999 was –5.4 percent compared with –4.6 percent for the latter.

- **Changes in U.S. R&D funding.** U.S. research funding patterns could explain the decline in article output. It is very difficult or impossible, however, to precisely match funding and publication by field, because the fields are classified and defined differently. In addition, scientists in a given funding field may publish their results in a journal that is classified in a different bibliographic field. For fields in which an approximate match could be made, the findings were inconclusive. For example, the fall in articles in biology and physical sciences coincided with a fall in Federal spending (in real terms) in these two fields. However, increases in funding for physics coincided with a decline in articles. Matching funding and publication by sector is more straightforward, because institutions are classified the same way. However, there appears to be no correlation between these two variables. Basic and applied research expenditures have increased in universities and the Federal Government, but article output has declined in these sectors. However, funding increases in the nonprofit institutions and nonprofit FFRDCs have coincided with increased article output in these sectors. A more precise match between NIH publication output and intramural expenditures reveals that the trend of funding and publication growth diverged in the early 1990s, with publication growth flattening as funding continued to increase.

- **Demography.** The U.S. scientific workforce has aged significantly since the 1970s. In the early 1970s, nearly half of all academic scientists and engineers were younger than age 40. Twenty years later, that figure had fallen to 28 percent, and by 1997, it had dropped to 25 percent. If age affects research productivity negatively, then this factor could provide a plausible explanation.[§] However, the apparent decline in publications did not occur until after this demographic shift had been well under way during the previous two decades.

- **Growth in foreign publishing.** During the 1990s there has been robust growth in foreign-authored publications. Scientific publications indexed to SCI have grown rapidly in many developed and several developing countries, notably in Western Europe, Latin America, and East Asia reflecting the growth in their production of S&E Ph.Ds. In addition, IT developments may have helped to level the playing field for scientists who were isolated or lacked access to relevant journals in their research fields, particularly in developing countries. Because there is limited space for high-quality articles, it may be that foreign publications are displacing U.S. publications. An indication of that possibility is shown by articles published in *Science* magazine. The number of U.S. papers in *Science* decreased by 5 percent between 1994 and 1999, while the total number of papers increased by 9 percent.

These and other factors will be the subject of further assessment of the nature of the trends affecting U.S. articles in the world's premier scientific and technical journals.

[†] Blumenthal, D., E.G. Campbell, M.P. Anderson, N. Causino, and K. Seashore Louis, 1997. "Withholding Research Results in Academic Life Science."

[‡] Florida, R. 1999. "The Role of the University: Leveraging Talent, Not Technology."

[§] Two studies reached different conclusions on this issue. See Blackburn, R. and J. Lawrence. 1986. "Aging and the Quality of Faculty Job Performance." *Review of Educational Research* (Fall): 265–90, and Levin, S., and P. Stephan. 1991. "Research Productivity Over the Life Cycle: Evidence for Academic Scientists." *American Economic Review* (March): 114–32.

figure 5-32 and appendix table 5-41.) Eastern Europe's share of worldwide output fell from 9 to 6 percent during this period. Publication volume in countries of the former Soviet Union dropped by one-third. This decline mirrors the economic and political difficulties that affected their scientific enterprise, including significant cuts in their R&D spending. In contrast, the Eastern European countries (Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia) experienced a much smaller decrease in articles, and in the mid-1990s, their output began trending upward. In Sub-Saharan Africa, output fell by 20 percent during this period, which reduced this region's share to less than 1 percent of world output. Countries that experienced significant declines included South Africa, which accounts for about half of the region's output, Nigeria, and Zimbabwe. However, several countries, including Cameroon, Cote d'Ivoire, Ethiopia, and Uganda, registered strong gains in their output, although these gains came from a very low base.

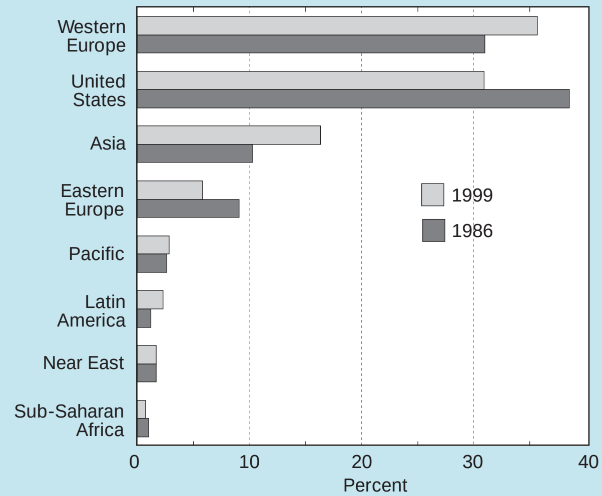
Notwithstanding the trend in the number of U.S. publications (see sidebar, "Trends in U.S. Scientific and Technical Articles"), the United States had the largest single share of worldwide publications in 1999, accounting for approximately one-third of the 530,000 articles in the 1985 SCI set of journals, more than triple the share of the next largest country, Japan. The United States and four other wealthy industrialized countries (Japan, Germany, the United Kingdom, and France) accounted for about 60 percent of worldwide publications in 1999. Japan, Germany, the United Kingdom, and France each had at least a 5 percent share of the worldwide output of articles, and on a per capita basis, their output was comparable with or exceeded that of the United States.

Nevertheless, the combined share of world output of the United States and these four countries declined from 64 to 60 percent during the 1986–99 period, due in large part to the apparent fall in U.S. articles, which reduced the U.S. share from 39 percent in 1986 to 31 percent in 1999. (See figure 5-35). The article share of Western Europe rose from 31 percent to 36 percent of world output during this period due to strong gains by most of these countries.

When the OECD and other high-income countries are added to the United States, Japan, Germany, the United Kingdom, and France, more than 80 percent of world output of the 1985 SCI journal set is accounted for. The predominance of these countries in scientific publications is consistent with their wealthy and technically advanced economies, extensive scientific and technical infrastructure, large pools of scientists and engineers, and comparatively high levels of expenditures for their science and engineering (S&E) enterprises.[35] However, increased S&T publishing in countries such as China, South Korea, Brazil, Mexico, and Argentina has increased the worldwide output of middle- and low-income countries. (See figure 5-36).

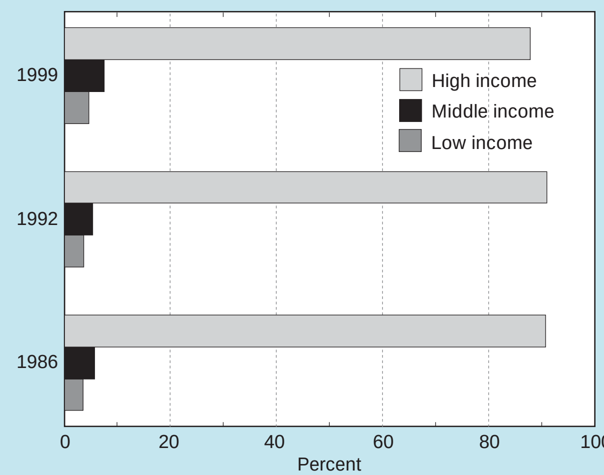
[35] Also see chapter 3, "Higher Education in Science and Engineering"; chapter 4, "U.S. and International Research and Development: Funds and Alliances"; and chapter 6, "Industry, Technology, and the Global Marketplace."

Figure 5-35.
Scientific publications: Regional share of world output



See appendix table 5-41. *Science & Engineering Indicators – 2002*

Figure 5-36.
Country share of world scientific publications, by income level



NOTE: Countries without World Bank income classification and new countries are excluded.

SOURCES: Articles: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Science Indicators database. Country income: The World Bank, World Development Indicators 2000.

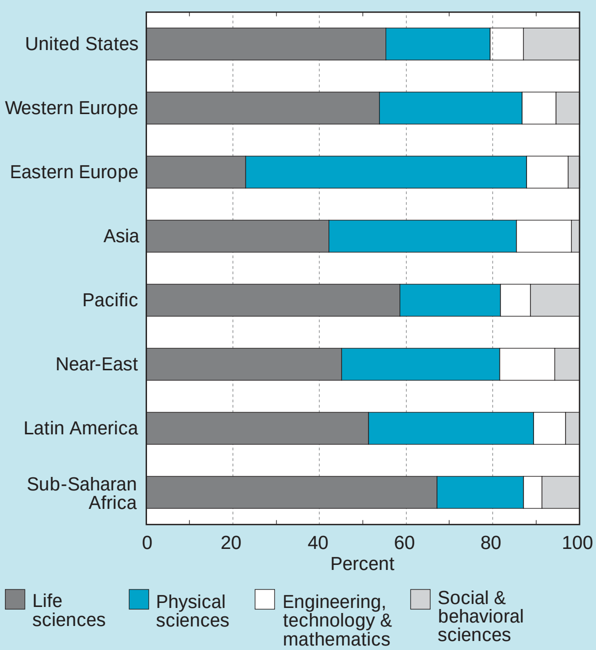
Science & Engineering Indicators – 2002

Examining the portfolio of scientific papers across regions and countries provides an indication of the priorities and emphasis of scientific research. The U.S. portfolio is broad and diverse, although dominated by life sciences. This pattern is similar to that of other OECD countries, but for major European nations the physical sciences shares are larger than in the

U.S. (See figure 5-37 and appendix table 5-43.) The life sciences (clinical medicine, biomedical research, and biology) accounted for more than half (55 percent) of all U.S. articles published in 1999. Their share has remained roughly constant over the past two decades, with marginal gains by clinical medicine and biomedical research offsetting a small loss by biology. Another one-quarter of the 1999 articles were produced in the physical and environmental sciences (chemistry, physics, and earth and space sciences) and mathematics. These fields registered a slight gain of three points compared with 1986. The remainder of the portfolio is accounted for by engineering and technology (6 percent) and social and behavioral sciences (13 percent), consisting of social sciences, psychology, health, and professional fields. The latter two fields have close ties (based on citations) to the former two fields.

The portfolio distribution in Western Europe and the Pacific is similar to that of the United States, except that physical sciences have greater prominence in Western Europe. (See figure 5-37.) Articles in physical sciences increased slightly in Western Europe between 1986 and 1999, while articles in life sciences decreased. In Asia, the physical sciences and engineering and technical fields were more prominent and life sciences and social sciences less so, especially in NIEs, China, and India. In these countries, life sciences accounted for one-quarter of the portfolio and physical sciences for more than half. The portfolios of the Asian NIEs underwent sizable shifts,

Figure 5-37.
Portfolio distribution of scientific and technical publications, by region: 1999



NOTES: Life sciences consist of clinical medicine, biomedical research, and biology. Physical sciences consist of chemistry, physics, and earth and space sciences. Social and behavioral sciences consist of social science, psychology, health, and professional fields. Computer sciences is included in engineering and technology.

See appendix table 5-43. *Science & Engineering Indicators – 2002*

with the share of physical, engineering and technical, and mathematical sciences growing dramatically from 40 percent of total output to more than 54 percent, largely due to an 11 percent share increase by physics. During the same period, the share of social and behavioral sciences declined from 12 to 3 percent. In contrast, Japan's portfolio is closer to that of Western Europe, with greater emphasis in life sciences (half of all articles) and less emphasis in the engineering and technical field.

In Eastern Europe and the former Soviet Union, the portfolio mix is similar to that of Asia, with physical sciences accounting for more than half of the total article output. The portfolio has shifted notably during this period; the share of life sciences declined from 36 to 23 percent, while that of physical sciences rose from 56 to 65 percent. The Near East region's portfolio is similar to that of Asia and Eastern Europe, with greater prominence of articles in physical sciences, which have increased relative to life sciences over the past two decades. Sub-Saharan Africa has the highest regional share of output in life sciences in the world (67 percent) and the smallest share in engineering and technology. The portfolio mix in Latin America is similar to that of Western Europe, with life and physical sciences being prominent, although the mix has shifted to a greater share for physical sciences relative to the life and social sciences.

In the United States, universities were the primary institutional source of publications (74 percent) in 1999, followed by much smaller shares from the Federal Government (7 percent), private for-profit (8 percent), private nonprofit (7 percent), and federally funded research and development centers (FFRDCs) (3 percent). (See figure 5-38.) Examining the data by field of science shows that the academic sector produced a greater-than-average share of articles in the fields of biomedical research, mathematics, and the social and behavorial sciences. Industry articles were prominent in physics, engineering and technology, and chemistry. Articles published by the Federal Government were prominent in the fields of biology, clinical medicine, and earth and space sciences. The nonprofit's portfolio was dominated by clinical medicine.(See appendix table 5-44).

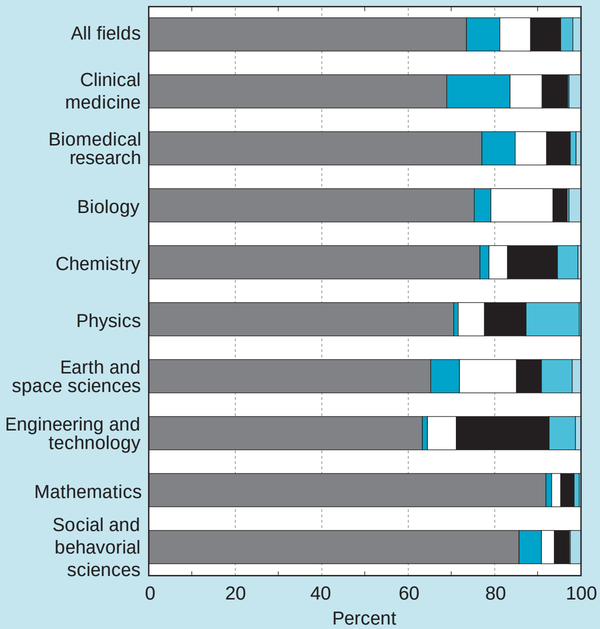
Scientific Collaboration

Scientific collaboration within and across national borders has increased significantly in the last two decades. Worldwide, more than half of all articles were coauthored[36] in 1999 compared with 37 percent in 1986. During the same period, the share of internationally coauthored articles rose from 7 to 17 percent of all publications; i.e., more than one-third of coauthored articles were internationally coauthored. Several factors have been driving the rise in collaboration:

- **IT.** Advances in IT have helped to reduce the geographical and cost barriers to domestic and international collaboration. E-mail greatly facilitates collaboration by allowing rapid exchange of information and eliminating the need for costly face-to-face meetings. The increasing use of high-capacity networks allows researchers to exchange

[36]A paper is considered co-authored when it has authors from different institutions. "Internationally coauthored" papers have at least one international institutional author. See "Data Sources for Article Outputs" on pg. 56-57.

Figure 5-38.
U.S. authorship, by sector: 1999



FFRDCs = Federally Funded Research and Development Centers

NOTES: Social and behavorial sciences consist of social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

huge data files, and improvements in software permit researchers to share research findings or conduct research on-line without requiring a centralized laboratory. (See also the “IT and R&D” section in chapter 8).

- **Economic growth.** Technology is increasingly recognized as a key determinant of economic growth by most nations, and the lag between scientific research and practical applications appears to have narrowed. In an environment of liberalization of trade and investment, scientific collaboration allows countries to acquire scientific and technological proficiency to maintain their competitive advantage or compete in new markets. For established scientific nations, domestic and international collaboration affords benefits such as cost savings, the potential to make faster progress, the ability to apply different or multidisciplinary approaches to problems, and the ability to stay abreast of advances made in related fields and other countries. Domestic and international collaboration allows nations with smaller or less developed S&T systems, to leverage and boost their indigenous capacity and provides a means to acquire knowledge from more advanced nations.

- **Scale, cost, and complexity of scientific research.** As the scale, cost, and complexity of attacking many problems have increased, research teams have become common, changing the structure of the research. Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. Moreover, the scale, cost, and complexity of some of today’s scientific problems, such as mapping the human genome, studying global environmental trends, or constructing an observatory in space, invite or often compel domestic and international collaboration.

- **Politics.** The end of the cold war has allowed countries to establish and/or renew political, economic, and scientific ties that previously were not possible. The dissolution of the former Soviet Union also increased the number of collaborating countries. In addition, a web of intergovernmental agreements invites or requires multinational participation in some research activities.

- **Education.** The extent of the advanced training students receive outside their native countries also appears to be a factor.[37] Relationships established between foreign students and their teachers can form the basis of future collaboration after the students return to their native countries. IT facilitates this type of collaboration.

Collaboration Within the United States

Work produced by single authors is in decline in virtually all fields, and the proportion of U.S. scientific and technical articles by multiple authors has continued to rise. In 1999, 60 percent of all S&E articles had multiple authors, up from 48 percent in 1988. This reflected an approximate 30 percent decrease in the number of U.S. articles by single authors and a corresponding increase in the number of articles by multiple authors. This general pattern held for all but psychology and social and behavioral sciences; in that group output by authors from the same institution fell and from authors from multiple institutions was static. (See appendix table 5-45.) Multiple authorship was highest in clinical medicine, biomedical research, earth and space sciences, and physics (ranging from 63 to 69 percent), and lowest in the social sciences, psychology, and chemistry (ranging from 35 to 48 percent).

Collaboration across institutions in the United States is extensive. The Federal Government has long sought to stimulate this trend in several ways, for example, by promoting collaboration across sectors (e.g., industry-university or FFRDC-industry activities). Such cross-sector collaboration is seen as enriching the perspectives of researchers in both settings and as a means for more efficiently channeling research results toward practical applications.

In 1999, cross-institution or -sector collaboration (the share of multi-authored papers authored in different sectors as a percentage of all multi-authored papers was 77 percent or greater for all institutions except the academic sector. (Text

[37]See chapter 3, “Higher Education in Science and Engineering.”

Text table 5-18.
U.S. sector cross-collaboration: 1999
(Percentage)

Sector	Share of sector's coauthored papers with other sectors	Share of sector's cross-sectoral collaborated papers: Academic	Federal Government	Private for-profit	Private nonprofit	FFRDC	Other government
Academic	37	NA	32	25	36	13	6
Federal Government	81	87	NA	14	14	6	3
Private for profit	77	82	17	NA	16	7	2
Private nonprofit	79	90	13	13	NA	3	3
FFRDC	80	85	14	14	7	NA	0
Other government	92	86	19	11	20	1	NA

FFRDC = Federally Funded Research and Development Center, NA = not applicable

NOTES: Shares based on whole counts of publications, where each institutional author is assigned a whole count. This counting methodology results in the sum of sector shares exceeding 100 percent because some coauthored papers involve collaboration across more than two sectors. FFRDC includes FFRDCs administered by university, industry, and nonprofits.

See appendix table 5-46.

Science & Engineering Indicators – 2002

table 5-18 and appendix table 5-46.) The academic sector was at the center of cross-sectoral collaboration in every sector and field, although the academic sector itself had a much lower cross-sectoral share (37 percent), because the majority of its collaboration occurred among institutions of higher education. Cross-sector coauthorship rates with academia (the percentage of a sector's cross-sector coauthored papers with an academic collaborator) were at least 82 percent for other sectors.

Distinct collaborative relationships exist by field of science, as measured by the share of cross-institutional papers:

- **Clinical medicine.** This field is characterized by a high degree of collaboration across institutions (as well as a high share of multiauthored papers). Important partnerships in this field include universities and the Federal Government with nonprofit organizations and FFRDCs and the Federal Government and nonprofit organizations.
- **Biomedical research.** The private sector is a key collaborator with other institutions, with nonprofits authoring papers with academia and the FFRDCs and industry partnering with the Federal Government and nonprofits.
- **Biology.** Although the proportion of multiauthored papers is lower than for other life sciences, cross-institutional papers are a significant share of these multiauthored papers. Similar to biomedical research, the private sector is a key collaborator, authoring papers with the Federal Government, academia, and nonprofits. In addition, academia and the FFRDCs are significant collaborators.
- **Chemistry.** Industry is a key collaborator, authoring papers with nonprofit organizations, academia, and the Federal Government.
- **Earth and space sciences.** This field has the highest share of multiauthored papers, including collaboration across sectors. The Federal Government and FFRDCs have prominent ties to the private sector in this field.
- **Engineering and technology.** This field is similar to biology, with a lower share of multiauthored papers but a higher-than-average share of cross-sector papers. Industry is a collaborator with academia, FFRDCs, and the Federal Government. In addition, FFRDCs have prominent ties with the academic sector.
- **Physics.** The Federal Government has prominent ties to FFRDCs and industry in this field.

International Collaboration

International collaboration increased greatly over the past two decades, as indicated by multiauthor articles with at least one international author. From 1986 to 1999, the total number of internationally coauthored articles increased by 14 percent, while multiauthored papers rose by 65 percent, raising the share of multiauthor articles from 37 percent to more than half of total publications. Internationally coauthored papers nearly tripled in volume, raising their share from 20 to 32 percent of multiauthored papers. In 1999, 17 percent of scientific articles had at least one international author.

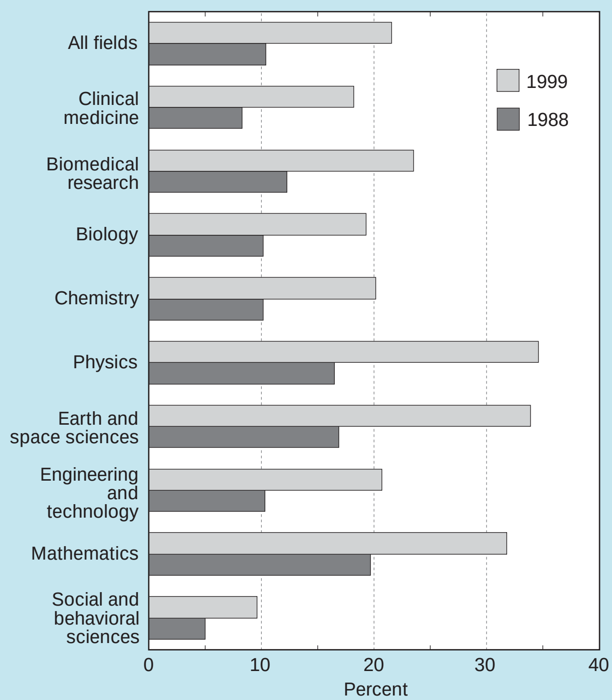
Patterns of international coauthorship provide one indication of the extent of collaborative ties among nations and regions. By this indicator, several trends in international collaboration are evident:

- The dominant centers in the production of S&T papers, the United States, Western Europe, Japan, and several other Asian countries, are centers of international scientific collaboration. A substantial part of these countries' international collaboration is with the other countries in this group.
- The remaining regions of the world with largely developing and emerging economies (Eastern Europe, the Near East, North and Sub-Saharan Africa, and Latin America) conduct most of their collaboration outside their regions with the United States, Western Europe, and Asia.

U.S. International Collaboration. Almost all the increase in coauthored U.S. articles reflected rising international collaboration. By 1999, 1 article in 5 had at least one non-U.S. author, compared with 1 article in 10 in 1988. (See figure 5-39.) Rates of international coauthorship were highest for physics, the earth and space sciences, and mathematics, ranging from 32 to 35 percent of all U.S. articles. International collaboration rates were much lower (10 percent) in social and behavioral sciences.

United States authors participate prominently in international collaborations. In 1999, 43 percent of all published papers with at least one international coauthor had one or more U.S. authors. U.S.-international coauthorships encompass not only the world's major scientific countries but also many developing and emerging economies. This included countries with low overall rates of international collaboration. In 1999, U.S. researchers published collaborative scientific papers with researchers from 160 countries—almost every country in the world that authored international scientific papers. (See appendix table 5-47).

Figure 5-39.
U.S. international collaboration, by field



NOTES: Social and behavioral sciences consist of social science, psychology, health, and professional sciences. Computer science is included in engineering and technology. Field volume is in terms of whole counts, where each collaborating institutional author is assigned an entire count.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

With few exceptions, U.S. coauthorship with Western Europe is extensive. This share ranged from 23 to 35 percent, including the three Western European countries with the highest output of scientific publications: the United Kingdom (29 percent), Germany (30 percent), and France (25 percent). (See text table 5-19 and appendix table 5-48.) U.S. coauthorship

Text table 5-19.
International coauthorship with the United States: 1986 and 1999
(Percentage)

Country/economy	U.S. share of country's internationally coauthored articles: 1999	1986
Taiwan	60	67
South Korea	57	67
Israel	53	68
Canada	51	53
Mexico	43	56
Japan	42	56
Brazil	40	38
India	37	37
Kenya	37	36
New Zealand	37	38
Australia	37	40
Uganda	36	36
Turkey	35	40
Chile	35	47
Egypt	34	40
Singapore	33	28
Italy	32	36
Switzerland	32	32
South Africa	32	37
Argentina	30	44
China	30	51
Germany	30	35
Netherlands	30	30
United Kingdom	29	35
Hong Kong	29	64
Norway	29	29
Finland	28	34
Denmark	28	28
Hungary	28	25
Sweden	27	36
Poland	25	21
Russia	25	na
Spain	25	29
France	25	29
Ireland	25	24
Belgium	23	28
Czech Republic	22	na
Nigeria	21	34
Ethiopia	18	13
Malaysia	10	24

na = not applicable

NOTES: U.S. internationally coauthored articles involve at least one U.S. author. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

rates with Asia were generally higher than with Western Europe, ranging from 30 to 60 percent (with a few exceptions) of each country's internationally coauthored papers. U.S. collaboration was especially high with NIEs (Taiwan at 60 percent, South Korea at 57 percent, and Singapore at 33 percent); China at 30 percent; and two countries that have low overall rates of international collaboration, Japan at 42 percent and India at 37 percent. U.S. coauthorship rates with Latin American countries were similar to those of Asia, ranging from 20 to 60 percent in most countries in this region. This includes the countries of Argentina and Brazil, which have a significant share of regional output but a lower overall rate of international coauthorship than other countries in this region.

U.S. coauthorship rates with Sub-Saharan Africa and the Near East varied widely, from less than 10 percent to greater than 60 percent. However, the United States tended to have a relatively high rate of collaboration with countries that have significant regional output, such as Israel (53 percent), Egypt (34 percent), Kenya (37 percent), and South Africa (32 percent) U.S. coauthorship rates with Eastern Europe were lower, generally ranging from 15 percent to 38 percent, such as Hungary (28 percent), Poland (25 percent), Russia (25 percent), and the Czech Republic (22 percent) in 1999.

The countries which had the highest rate of collaboration with the U.S., as measured by their share of U.S. international articles, were largely those with mature S&T systems. Of the top 10 countries, 6 are in Western Europe; Germany (14 percent), the United Kingdom (12 percent), France (9 percent), Italy (7 percent), Switzerland (4 percent), and the Netherlands (4 percent). (See text table 5-20.) Japan is also a significant collaborator, with a 10 percent share of U.S. international papers. Of these countries, Germany, the United Kingdom, Japan, and France have the highest worldwide share of output after the United States. Canada and Australia are significant collaborators, with shares of 11 and 5 percent, respectively. Russia, with a share of 4 percent, rounds out the top 10 countries.

Little change occurred in these countries' shares of articles coauthored with the United States as compared with the previous decade, except for Russia, which established strong institutional partnerships with the United States during that period. Another important change in U.S. ties is the growing partnership with the Asian NIEs. Although no single NIE is among the top 10 countries, the NIEs have collectively increased their share of U.S. international articles from 2 percent in 1986 to 6 percent in 1999. The patterns of U.S. collaboration with the rest of the world also appear to reflect the ties of foreign students who received advanced training in the United States. (See figure 5-40.)

Compared with the previous decade, U.S. international collaboration declined slightly, falling from 51 percent in 1986 to 43 percent in 1999, as the volume of internationally coauthored papers expanded at a rate faster than the strong growth rate of U.S. coauthored international papers in almost all countries. This pattern, a robust expansion of U.S. coauthored papers accompanied by declining U.S. shares, held for almost all countries. This pattern suggests that new centers of activity and collaboration are evolving.

International Collaboration in the Rest of the World. International collaboration in the rest of the world followed trends similar to those of the United States. In most countries, the number of articles with multiple authors, especially those with at least one international coauthor, grew faster than the number of articles with single authors. This was generally due to an expansion in the volume of internationally coauthored articles and an increase in the number of collaborating countries. The scope of international collaboration among other nations can be seen in appendix table 5-47, which shows the total number of countries with any collaborating nondomestic author on a given nation's papers.

Text table 5-20.
U.S. international papers: top collaborating countries
(Percentage)

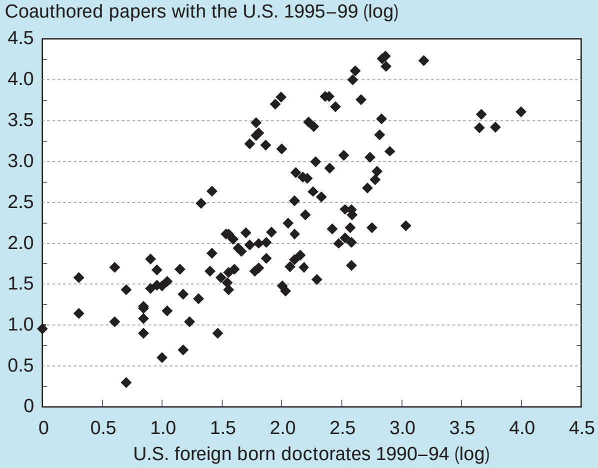
	1986			1999	
Rank	Country	Share	Rank	Country	Share
1	Canada	13.6	1	Germany	13.8
2	United Kingdom	13.3	2	United Kingdom	12.4
3	Germany	11.7	3	Canada	11.2
4	France	8.3	4	Japan	9.9
5	Japan	8.1	5	France	8.7
6	Israel	6.3	6	Italy	6.9
7	Italy	5.5	7	Australia	4.5
8	Switzerland	4.1	8	Switzerland	4.3
9	Sweden	4.0	9	Netherlands	4.2
10	Australia	3.9	10	Russia	4.1

NOTES: U.S. internationally coauthored articles involve at least one author from indicated countries. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

Figure 5-40.
Relationship of foreign-born U.S. doctorates to their country's scientific collaboration with the U.S.

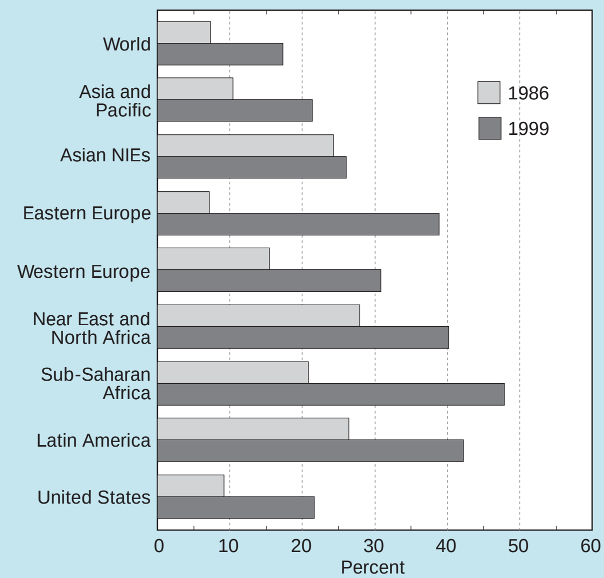


NOTE: This figure includes countries that have at least a .01 percent share of all internationally coauthored papers.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics. Ph.D's: National Science Foundation, Survey of Earned Doctorates.

Science & Engineering Indicators – 2002

Figure 5-41.
International scientific collaboration by region



NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Asia & Pacific excludes these countries.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

The table reveals a dramatic expansion of cross-national collaboration over the 13 years due to the creation of new countries and an increase in the number of partnerships with existing countries. A total of 50 countries (including 6 new nations) had ties to at least 50 or more other nations in 1999 compared with 15 in 1986.

The strong growth of collaborative activity occurred in developing and industrialized countries in every region. (See figure 5-41.) In Western Europe, articles by multiple authors rose strongly, increasing their share from 41 percent in 1986 to 60 percent of all publications in 1999. This increase was driven by a rise in internationally coauthored articles, which nearly tripled during this period. By 1999, articles with at least one international coauthor accounted for 31 percent of all publications, up from 16 percent in 1986. Countries in this region, many of which had extensive ties during the previous decade, continued to expand their partnerships. There were 8 Western European countries with ties to 100 or more nations in 1999, an evident sign of this region's extensive scientific collaboration with other nations. Much of the high degree of international collaboration in Western Europe reflects the extensive amount of intraregional collaboration among these countries. Intraregional collaboration increased in virtually all Western European countries between 1986 and 1999, as measured by the share of the countries' international papers with coauthored papers from other European countries. For example, the share of France's international papers with German coauthors increased from 11 to 15 percent; its share with coauthors from the United Kingdom increased from 11 to 14 percent; and its share with Italian coauthors rose from 8 to 11 percent. (See appendix table 5-49.) Outside their region, the Western European countries had a high degree of collaboration with the United States, Eastern Europe, and Asia, especially Japan.

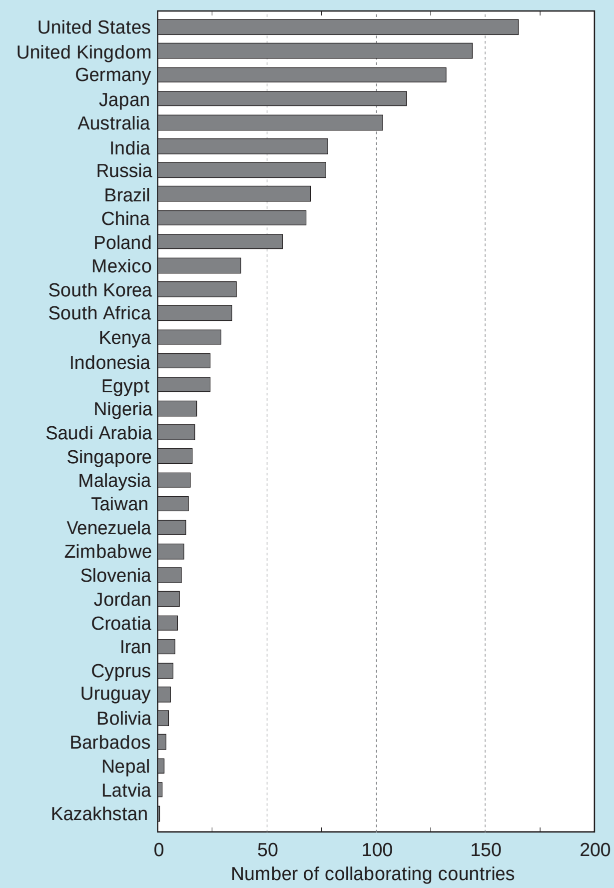
In Eastern Europe and central Asia, internationally coauthored articles grew during this period from less than 10 percent to almost 40 percent of these regions' articles. This jump in international collaboration reflects both a continuation of ties among countries that were part of the former Soviet Union and new partnerships with the rest of the world, especially scientifically advanced countries. For example, roughly one-quarter each of internationally coauthored papers in Russia and the Eastern European countries have at least one author from the United States or Germany. The Baltic states have developed strong collaborative ties with the Nordic states, reflecting the reestablishment of historical and regional connections.

In Asia and the Pacific (excluding the Asian NIEs), multiple authorship more than tripled during this period, largely due to an increase in international articles in these regions from 10 to 21 percent. The share of internationally coauthored papers in NIEs was also significant, accounting for more than one-quarter of their publications. Several Asian countries (Hong Kong, Singapore, Indonesia, and Malaysia) expanded their international ties threefold during this period, and India increased its ties to more than 100 countries in 1999. Greater intraregional collaboration was a significant factor in the increase in international collaboration, especially in China, NIEs, India, and other countries. (See appendix table 5-49.) For example, China's share of articles coauthored with Japan, Singapore, and South Korea rose from 12 to 16 percent, less than 0.5 to 3 percent, and 0.5 to 2 percent, respectively. Japan's rate of intraregional collaboration is much lower, but it also increased its partnerships with other countries in this region, notably with South Korea (from 2 to 5 percent) and China (from 4 to 7 percent). India is similar to Japan in its relatively low level of intraregional collaboration; however, its share of internationally coauthored articles with China, Japan, and the Taiwanese economy did rise. A high degree of collaboration outside the region occurs with the United States and Western Europe.

Gains in international collaboration led to a marked increase in coauthorship in Latin America and Sub-Saharan Africa. In 1999, the share of all papers in the region that were coauthored by at least one international author was nearly half in Sub-Saharan Africa and more than 40 percent in Latin America. These rates were substantially higher than in the previous decade. Intraregional collaboration among the Latin American countries also increased but remained modest in comparison with Western Europe or Asia. (See appendix table 5-49.) Argentina's share of papers coauthored with Mexico rose from 1 to 5 percent, and its share with Chile rose from 3 to 4 percent; however, its share with Brazil, its largest collaborator, fell by 3 percentage points, to 13 percent. Brazil's share with other countries in the region showed little change during this period, and its small shares with other countries attest to its pattern of collaborating largely outside the region. Mexico's collaboration increased with countries such as Argentina, Brazil, and Chile. Outside their own regions, these countries collaborate mainly with the United States and Western Europe, reflecting the importance of partnering with advanced countries with which they have educational, historical, and cultural ties.

Although international ties have expanded greatly, figure 5-42 shows that many countries tend to concentrate their collaborations in relatively few countries, most of which are developed countries with mature S&T establishments. The sharp drop-off in the number of countries collaborated with suggests that developing countries restrict much of their collaboration to major science-producing nations. The rise in intraregional collaboration in most developing regions suggests that their collaboration outside major science-producing nations is confined to developing countries in their own regions. It also suggests that countries with ties to large numbers of other countries, mainly those with a well-developed S&T infrastructure, conduct a large share of their collaboration with other major science producers, and their share with developing nations is a much lower portion of their total collaboration.

Figure 5-42.
Breadth of international scientific collaboration by country: 1999



NOTE: Number of countries that shared at least 1 percent of their internationally coauthored papers with indicated country.

See appendix table 5-47. *Science & Engineering Indicators – 2002*

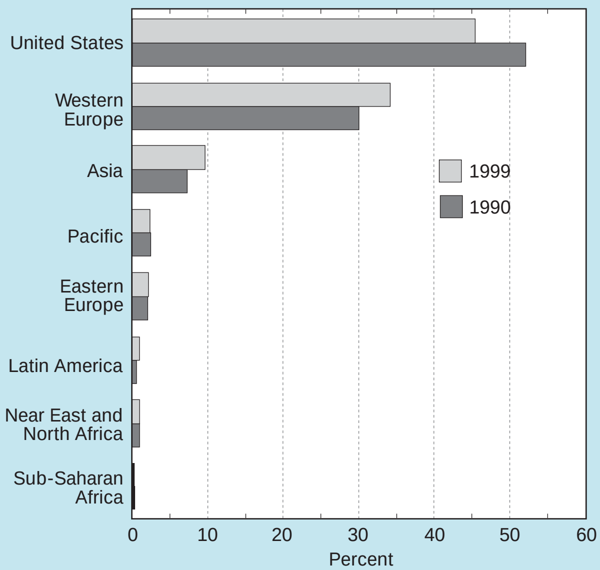
International Citations to Scientific and Technical Articles

The global dimensions of scientific activity, discussed above in terms of international research collaboration, also are reflected in the patterns of citations to the literature. Scientists and engineers around the world cite previous work done elsewhere to a considerable extent, thus acknowledging the usefulness of this output for their own work. Citations, aggregated here by region, country, and field, thus provide an indicator of the perceived influence of a nation's scientific outputs to other countries' scientific and technical work.[38] Citations to the work done in one's own country are generally prominent and show less of a time lag than citations to foreign outputs.

Citations within scientific papers to scientific research are dominated by the major science paper producers: the United States, Western Europe, and Asia. (See figure 5-43.) Scien-

[38]Citations are not a straightforward measure of quality because of self-citations by authors; authors citing colleagues, mentors, and friends; and a possible non-linear relationship of a country's number of publications and citations to that output.

Figure 5-43.
Scientific research cited by scientific and technical papers, by region



See appendix table 5-47. *Science & Engineering Indicators – 2002*

tific research from these regions accounts for nearly 90 percent of all cited research. U.S. literature is the most widely cited, although its share fell in the last decade from 52 percent in 1990 to 45 percent in 1999, a decline similar in magnitude to that of the fall in its world share of scientific literature. Meanwhile, the share of cited literature from Western Europe and Asia grew during this period at a magnitude comparable to that of the rise in their share of scientific papers. The increase in the shares of these two regions was driven by many of the same countries that increased their production of scientific papers. In Western Europe, countries such as Germany, France, Italy, Switzerland, the Nordic countries, Spain, and Portugal increased their world share of cited literature. (See appendix table 5-50.) In Asia, the rise in share was driven by countries such as Japan and China and by NIEs. Latin America, which had the fastest growth rate in scientific papers, was the only developing region whose world share of cited literature rose, increasing from 0.6 percent in 1990 to 1 percent in 1999.

Adjusted for its world share of scientific papers, U.S. literature is the most often cited in the world compared with other regions. Over the past two decades, on average, the U.S. share of cited scientific research has been 35 percent greater than the U.S. share of scientific literature. Although the world share of U.S. literature and citations to U.S. literature have declined, the perceived influence of U.S. science remains high on a relative basis. (See text table 5-21 and appendix table 5-51.) The prominence of cited U.S. literature reflects, to a considerable extent, the even higher propensity of U.S. scientists to cite their own literature. U.S. literature, however, is the most highly cited literature by most other regions of the world and is especially prominent in Western Europe, the Near East, and the Asian NIEs. Western European literature is also highly cited by the United States and other regions, especially by Eastern Europe. Although U.S. and Western European literature are generally the most highly cited by developing regions, Latin America and Sub-Saharan Africa each cite the other's literature at a fairly high rate.

Text table 5-21.
Relative prominence of citations to U.S. scientific publications, by region

	Relative citation index	
Citing country/region	1990	1999
World	1.36	1.35
United States	1.84	1.94
Western Europe	0.98	1.02
Asia and Pacific	0.95	0.99
Asian NIEs	1.07	1.10
Eastern Europe	0.78	0.78
Near East	1.15	1.08
Latin America	1.04	0.97
Sub-Saharan Africa	0.82	0.85

NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Relative citation indexes are frequency of citations to U.S. literature by each region adjusted for U.S. share of scientific papers. A value of 1.00 would indicate that the U.S. share of cited literature is equivalent to the U.S. share of published literature in the world.

SOURCE: CHI Research, Inc.

Science & Engineering Indicators – 2002

Text table 5-22.
Relative prominence of cited scientific literature, by country

Rank	Country	1990	1999
1	Switzerland	1.46	1.37
2	United States	1.36	1.35
3	Netherlands	1.13	1.12
4	Sweden	1.14	1.07
5	Denmark	1.03	1.04
6	United Kingdom	1.06	1.04
7	Finland	0.89	1.02
8	Germany	0.99	1.01
9	Canada	0.93	0.99
10	Belgium	0.98	0.95
11	France	0.94	0.93
12	Austria	0.94	0.91
13	Italy	0.81	0.88
14	Australia	0.94	0.87
15	Israel	0.80	0.84

NOTES: Countries ranked by their relative citation index in 1999. Relative citation indexes are the citations by the world's scientific papers to the country's scientific literature, adjusted for the country's share of scientific papers. A value of 1.00 would signify that the country's share of cited literature is equivalent to its share of published literature in the world.

See appendix table 5-51. *Science & Engineering Indicators – 2002*

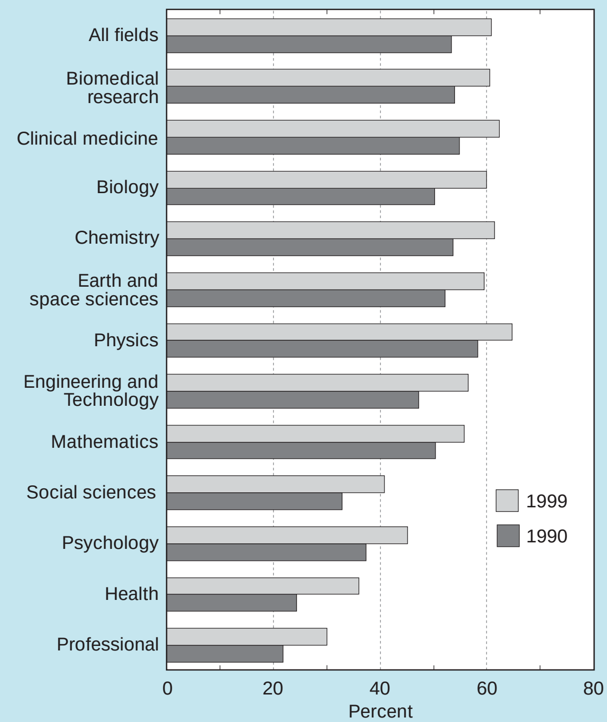
Adjusted for country share of world literature, the most frequently cited countries are major science producers and members of OECD (see text table 5-22 and appendix table 5-52):

- Switzerland is the most highly cited country in the world and is the largest producer of scientific papers on a per capita basis. (See appendix table 5-42.) It is the top-cited country in engineering and technology (with an especially high index of 1.8) and biology, and shares the top spot with the United States in biomedical research.
- The United States is a close second to Switzerland, with U.S. papers the most frequently cited in physics, clinical medicine, biomedical research (tying with Switzerland), chemistry, and earth and space sciences. It is also highly cited in the social and behavioral sciences. Citations to U.S. literature are relatively fewer in biology compared with other fields.
- The Nordic countries, the Netherlands, and Denmark also are very highly cited countries across many fields of science.
- The United Kingdom is highly cited in social and behavioral sciences, along with the United States.

In contrast to OECD countries, developing and emerging countries are cited 25–75 percent less relative to their worldwide share of literature. Despite the high growth rates in article output in NIEs and China, their relative citation indexes, which are at 0.6 or less, did not rise in the 1990s. (See appendix table 5-52.) The lack of increase in the citation of their literature may reflect, in part, that their international ties have been concentrated with the United States and within their own regions. Another difference is that developing countries cite publications produced in their own regions at a much higher rate than do developed countries. For example, the self citation indexes in Latin America (11.4) and Sub-Saharan Africa (32.0) are much higher than their interregional citation indexes. (See appendix table 5-51.) This suggests that these regions lack access to scientific research outside their own regions, although important differences exist between them. Latin America's self-citation index fell markedly during the last decade, whereas its world share of citations increased, suggesting that this region increased its access to international science and that the perceived influence of Latin American research also increased in the rest of the world. Sub-Saharan Africa, on the other hand, continued to have a very high self-citation rate, but its rate of citation in the rest of the world improved only slightly. Although developing and emerging countries are less prominently cited across all fields, certain countries do have particular prominence, adjusted for their share of literature, that rivals that of OECD countries. For example, Chile is the second most-cited country in earth and space sciences, the Hong Kong economy is highly cited in chemistry and biology, and Slovenia is highly cited in mathematics.

The international nature of scientific research, as evidenced by the degree of international collaboration discussed in the previous section, is underscored by the high and growing share of citations to work done abroad. Averaged across all countries and fields, 61 percent of all citations in 1999 were to foreign research compared with 53 percent in 1990. (See figure 5-44.) This overall rate masks a much lower citation rate by the United States compared with much higher rates in the rest of the world. (See appendix table 5-53.) Many of the citations to foreign science are to publications outside each region, primarily to the publications of regions with a well-developed science base: the United States, Western Europe, and to some extent, Asia and the Pacific. The exception to this is Western Europe, where about half of the citations are intraregional, consistent with the region's high degree of intraregional collaboration. The rate of citing foreign science varies by field, with high shares in physics, mathematics, and engineering and technical fields, and the lowest shares in the social and behavioral sciences.

Figure 5-44.
Citations to foreign articles in the world's major scientific and technical journals, by field: 1990 and 1999



NOTES: Citations are for a three-year period with a two-year lag; for example, 1999 citations consist of 1999 articles citing articles published in 1995–97. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

Citations in U.S. Patents to Scientific and Technical Literature

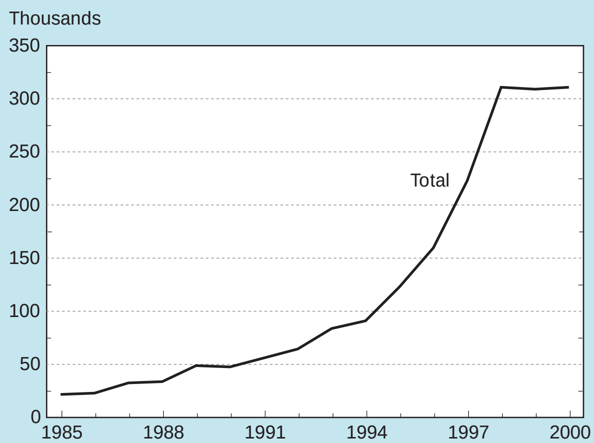
Patent applications cite "prior art"[39] that bounds the inventor's claims to the product or process to be patented. Citations to prior art have traditionally been to other patents; increasingly, these citations include scientific or technical articles. The percentage of U.S. patents that cited at least one such article increased from 11 percent in 1985 to 24 percent in 1997, before falling to 21 percent in 2000.[40] This development attests to both the growing closeness of some research areas, for example, life sciences, to practical applications and the increasing willingness of the U.S. Patent and Trademark Office (PTO) to award "upstream" patents, that is, research-driven products and processes that have less immediate commercial application, such as genetic sequencing. Thus, citations of scientific and technical articles provide an indicator of the growing link between research and innovative application, as judged by the patent applicant and recognized by PTO.[41]

[39]A U.S. Patent application is evaluated on whether it is useful, novel, and non-obvious. The novelty requirement leads to references to other patents, scientific journal articles, meetings, books, industrial standards, technical disclosure, etc. These references are termed "prior art."

[40]Personal communication with Kimberly Hamilton, CHI Research, Inc.

[41]Some caveats apply. The use of patenting varies by industry segment, and many citations on patent applications are to prior patents. Industrial patenting is only one way of seeking to ensure firms' ability to appropriate returns to innovation and thus reflects, in part, strategic and tactical decisions (e.g, laying the groundwork for cross-licensing arrangements). Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future. (See Geisler 2000.)

Figure 5-45.
Number of citations in U.S. patents to scientific and technical articles: 1985–2000

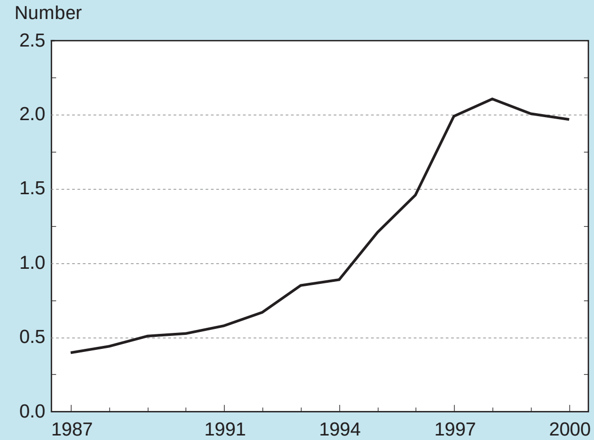


NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references of U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

Figure 5-46.
Average number of citations to scientific and technical articles per U.S. patent: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

The number of patent citations to articles appearing in any of the world's scientific and technical literature increased rapidly since the mid-1980s. They stood at about 22,000 in 1985, reached almost 123,000 in 1995, then more than doubled to reach more than 310,000 in 1998. (See figure 5-45.)[42] Even as the number of patents rose rapidly, the average number of citations per U.S. patent increased more than fivefold during this period. (See figure 5-46.) The rapid growth of citations ceased in 1999–2000, with total and average citations falling slightly in each of these two years.[43]

Citations to research articles were matched to a subset of approximately 5,000 of the world's most important scientific and technical journals to ascertain information about these citations: scientific field, country of publication and inventor, and performing sector (which is referenced to a smaller subset of U.S. literature) for all U.S. patents issued from 1987 through 2000. Although this eliminates references to other journals, this restricted set of citations helps provide insight on the factors driving this rapid growth of citations.

The rapid growth of article citations in patents throughout much of the past decade was centered in huge increases in the life science fields of biomedical research and clinical medicine. In 1987, each of these fields had about 3,000 citations; by

[42]The number of citations is based on scientific and technical articles published in a 12-year span that lagged 3 years behind issuance of the patent. For example, 2000 patent citations are to articles published in 1986–97, and so forth.

[43]The growth of citations likely has been influenced by changes in PTO procedures, regulations, and legal precedent. See sidebar, "The Growth of Referencing in Patents."

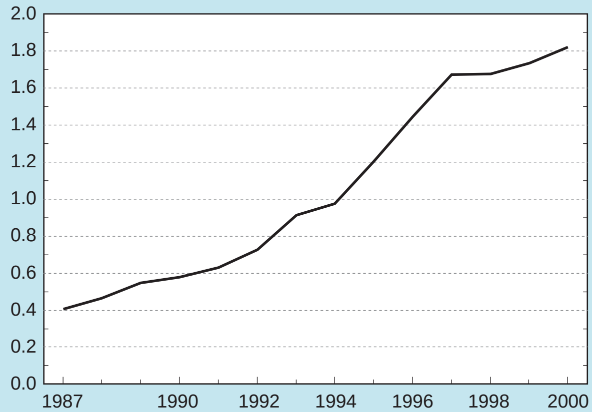
The Growth of Referencing in Patents

During the past decade, the rate at which patents reference scientific papers has increased rapidly. The causes of this growth are complex, but they appear to include 1995 changes in patent law. These changes, enacted to comply with the General Agreement on Tariffs and Trade (GATT), changed the term of protection from 17 years from the award date to 20 years from the filing date for applications received after June 8, 1995. Previously rejected patents refiled after this date would also be subject to the GATT rules. Applications submitted to the U.S. Patent and Trademark Office (PTO) more than doubled in May and June of 1995. These applications carried an unusually large number of references to scientific material. Patents applied for in June 1995 carried three times the number of science references as those from March 1995 and six times the number as those from July 1995. This sudden increase in referencing affected patents in all technologies, not just those in biotechnology and pharmaceuticals, in which referencing is most extensive.

The surge in applications during this period suggests that applicants and their attorneys rushed to file their patents under the old rules, perhaps out of caution and uncertainty about the GATT rules. One source of uncertainty in the application process at the time, affecting especially biotechnology, was ambiguity about what constituted adequate written description. Because a rejected application would have to be refiled under the GATT rules, referencing a great deal of scientific material may have been a strategy to minimize the chance of rejection because of lack of adequate written description.

Patents applied for in May and June 1995 were issued gradually over the next few years. As these patents were issued, the rate of referencing increasing rapidly. However, after the last of these applications were processed, the rate of referencing fell again to levels more nearly like those found earlier. In fact, if these patents are eliminated from consideration, a more gradual long-term trend of increased referencing is evident. (See figure 5-47.)

Figure 5-47.
Science references per U.S. patent excluding "spike" patents: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. "Spike" patents are those with an application date of May–June 1995 and are excluded from this count.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office, CHI Research, Inc., Science Indicators and patent databases, and National Science Foundation, Division of Science Resources Statistics.

Science & Engineering Indicators – 2002

2000, the number had risen to more than 60,000 in biomedical research and more than 40,000 in clinical medicine. Citations to these two fields accounted for about 70 percent of all citations in 2000. Although citations in other fields also increased, the huge increases in clinical medicine and biomedical research resulted in big shifts in field shares (see appendix table 5-54):

- ♦ The share of biomedical research citations rose from 24 percent in 1987 to 45 percent in 2000; clinical medicine rose from 23 to 29 percent, respectively.
- ♦ The combined share of physics, chemistry, and engineering and technology citations dropped from 49 to 22 percent between 1987 and 2000.

The bulk of patents citing scientific literature were issued to U.S. inventors, who accounted for 64 percent in 2000. The U.S. share has increased slightly over the past two decades. This share is disproportionately higher than the U.S. share of all patents. The share of Asian inventors, however, is disproportionately lower than their share of total U.S. patents. Other key inventor regions and countries of patents that cite scientific literature include Western Europe (17 percent), including France (3 percent), Germany (4 percent), and the United Kingdom (4 percent), Japan (12 percent), NIEs (2 percent), and Canada (3 percent). Since the late 1980s, the share of U.S. patents issued to Western European and Japanese inventors fell 3 to 4 points, while the share by the NIE's rose from almost zero to 2 percent in 2000. (See text table 5-23.)

Articles authored from the academic sector were the most widely cited in U.S. literature,[44] accounting for 60 percent in 2000, and were prominently represented in the life science fields, particularly biology. The rapid increase of citations to this sector increased its share from just below half in 1987, whereas shares fell in all other sectors. (See appendix table

[44] U.S. performer data is restricted to citations of U.S. literature in the ISI journal set.

Text table 5-23.
Inventor nationality of U.S. patents that cite scientific literature

Nationality of inventor	2000: U.S. patents citing scientific literature	2000: All U.S. patents	1994: U.S. patents citing scientific literature	1994: All U.S. patents	1988: U.S. patents citing scientific literature	1988: All U.S. patents
Number of U.S. patents	13,945	157,497	7,589	101,676	4,572	77,924
Percentage share of patents						
World	100.0	100.0	100.0	100.0	100.0	100.0
North America	66.9	56.2	62.3	57.1	62.2	53.9
Canada	2.5	2.2	1.6	2.0	1.6	1.9
United States	64.4	54.0	60.7	55.1	60.6	52.0
Western Europe	16.9	16.7	16.5	16.9	20.4	22.9
Germany	4.4	6.5	5.1	6.6	6.6	9.4
France	2.7	2.4	3.4	2.7	3.7	3.4
Italy	0.9	1.1	1.0	1.2	1.4	1.4
Netherlands	1.0	0.8	1.1	1.0	0.9	0.8
Switzerland	0.9	0.8	1.3	1.1	1.6	1.6
United Kingdom	3.8	2.3	2.6	2.2	4.2	3.3
Asia	14.1	25.3	19.7	24.5	15.8	21.6
Japan	11.8	19.9	18.9	22.0	15.5	20.7
Asian NIEs	2.0	5.3	0.7	2.5	0.1	0.8
Other	2.1	1.8	1.6	1.4	1.7	1.7

NOTES: Asian NIEs are newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. The number of U.S. patents and nationality of inventor is based on U.S. patents that reference scientific articles in approximately 5,000 journals classified by the Institute of Scientific Information.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; Institute for Scientific Information; CHI Research, Inc., Science indicators and patent database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

5-55.) The increase in citations to academic articles was particularly strong in physics (28 to 46 percent); the earth and space sciences (40 to 64 percent); and engineering and technology (25 to 49 percent), which are fields with stagnating or declining industry article output. Industry was the next most widely cited sector (20 percent share). Industry articles were prominently cited in the fields of physics and engineering and technology (42 percent for each field).

Life sciences, particularly biomedical research and clinical medicine, dominated nearly every sector, with from 67 percent to almost 100 percent of all citations. (See appendix table 5-55.) The composition of citations to industry articles in life sciences, in particular, illustrates the key role of these areas of inquiry. Sectors that had prominent citation shares in the physical sciences earlier in the decade (for-profit industry and FFRDCs) had significant declines in citations to these fields, while their share of life sciences citations grew significantly.

Examining the share of cited literature in the United States, Western Europe, and Asia adjusted for their respective shares of scientific literature reveals that inventors favor their own country or region. This is similar to the pattern of citations to scientific papers. U.S. literature, however, is highly cited by foreign inventors, a trend similar to the high frequency of citation of U.S. literature by non-U.S. scientists. U.S. literature is highly cited by Western European and Asian inventors, especially in the fields of chemistry, physics, clinical medicine, and biomedical research. (See text table 5-24.) In addition, Asian physics articles are highly cited by U.S. inventors and Asian engineering and technical articles are highly cited by Western European inventors.

Patents Awarded to U.S. Universities

The results of academic S&E research increasingly extend beyond articles in technical journals to patents protecting inventions deemed to be novel, useful, and nonobvious.[45] The Bayh-Dole University and Small Business Patent Act of 1980 provided a standard framework for university patenting, which a few institutions were already undertaking, and stimulated wider use of the practice. The act permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry.

Trends in academic patenting provide an indication of the importance of academic research to economic activity. The bulk of academic R&D is basic research, that is, it is not undertaken to yield or contribute to immediate practical applications. However, academic patenting data show that universities are giving increased attention to potential economic benefits inherent in even their most basic research and that PTO grants patents based on such basic work, especially in the life sciences.

The number of academic institutions receiving patents has increased rapidly since the 1980s after slow growth in the preceding decade but appears to have leveled off within the past several years to between 175 and 184. Both public and private institutions participated in this rise.[46] (See appendix table 5-56.)

[45] Research articles also are increasingly cited on patents, attesting to the close relationship of some basic academic research to potential commercial application. See the previous section, "Citations in U.S. Patents to Scientific and Technical Literature."

Text table 5-24.
U.S. patent citations of scientific literature relative to output of scientific literature: 2000

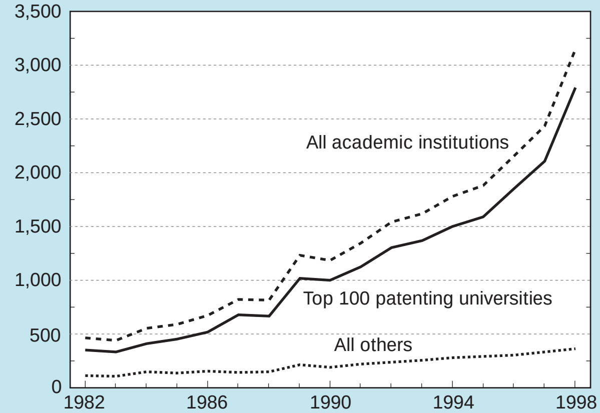
Citing inventor country/region	Cited literature: United States	Cited literature: Western Europe	Cited literature: Asia
All fields			
United States	1.86	0.67	0.60
Western Europe	1.33	1.20	0.57
Asia	1.22	0.60	2.53
Clinical medicine			
United States	1.61	0.67	0.63
Western Europe	1.19	1.11	0.56
Asia	1.20	0.47	3.15
Biomedical research			
United States	1.27	0.64	0.51
Western Europe	1.30	1.17	0.48
Asia	1.36	0.64	1.21
Biology			
United States	1.70	0.75	0.75
Western Europe	1.01	1.55	0.77
Asia	0.76	0.72	3.62
Chemistry			
United States	2.53	0.78	0.69
Western Europe	1.53	1.35	0.73
Asia	1.49	0.79	1.87
Physics			
United States	2.24	0.49	1.10
Western Europe	1.53	1.03	1.02
Asia	1.38	0.53	2.42
Engineering and technical			
United States	1.72	0.70	0.71
Western Europe	1.05	1.38	2.13
Asia	1.25	1.08	1.66

NOTES: County/region listed by its relative citation index, an indicator of the propensity of the inventor to cite literature adjusted for the inventor region/country's share of scientific literature. A value of 1.00 would signify that the country/region's share of cited literature by U.S. patents is equivalent to its share of published literature. Citations for 2000 are for a 12 year period with a three-year lag, i.e., 1986-1997 articles in the entire ISI journal set, which consists of approximately 5,000 journals. The share of the inventor country/region's publications in the world literature is on the basis of a more restricted fixed 1985 set of ISI journals. The difference in the coverage of the journal sets means that these indexes should be treated as approximate measures.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and patent database; and National Science Foundation, Division of Scientific Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

Figure 5-48.
Granted academic patents: 1982–98



NOTE: Top 100 patenting universities are determined by the sum of patents awarded during the 1990s.

See appendix table 5-55.

Science & Engineering Indicators – 2002

The expansion of the number of institutions was dwarfed by the steep rise in the number of patent awards to academia, from about 250–350 annually in the 1970s[47] to 3,151 in 1998, accelerating rapidly since 1995. (See figure 5-48.) As a result, academic patents now approach 5.0 percent of all new U.S.-owned patents, up from less than 0.5 percent two decades ago.

During the 1990s, the 100 largest recipients of academic patents accounted for more than 90 percent of the total. This reversed a trend during much of the 1980s, when many smaller universities and colleges began to receive patents, thus pushing the large institutions' share as low as 82 percent. (See appendix table 5-56.)

The vigorous increases in the number of academic patents largely reflect developments in life sciences and biotechnology (see Huttner 1999). Patents in a mere three application areas or "utility classes," all with presumed biomedical relevance,[48] accounted for 41 percent of the academic total in 1998, up from a mere 15 percent through 1980. (See figure 5-49.)

Academic institutions are increasingly successful in negotiating royalty and licensing arrangements based on their patents. Although total reported revenue from such licensing arrangements remain low in comparison to R&D spending, a

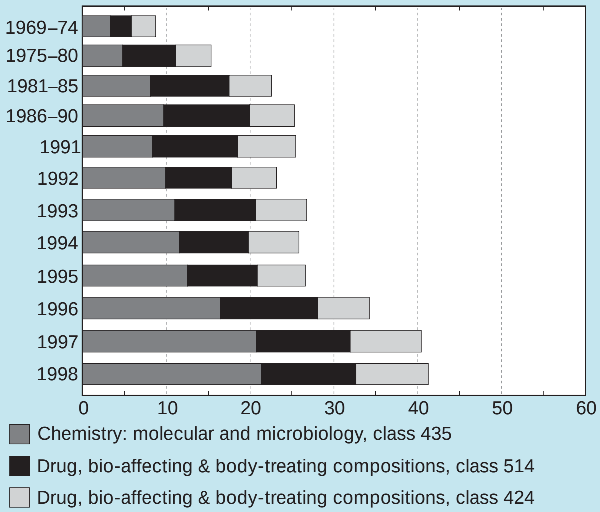
---

[46] It is difficult to be precise. Patent assignment depends on university practices, which vary and can change with time. Patent assignation may be to boards of regents, individual campuses, subcampus organizations, or entities with or without affiliation with the university. The data presented here have been aggregated consistently by PTO starting in 1982. The institution count is conservative, because several university systems are included in the count and medical schools are often counted with their home institutions.

[47] See National Science Board (1996), appendix table 5-42.

[48] Utility class numbers 424 and 514 capture different aspects of "Drug, bio-affecting and body treating compositions"; utility class number 435 is "Chemistry: molecular biology and microbiology." Patents are classified here according to their primary technology class.

Figure 5-49.
Percent of total academic patents in three largest academic utility classes: 1969–98



SOURCES: U.S. Patent and Trademark Office, TAF Report: U.S. Universities and Colleges; and NSF, Division of Science Resources Statistics, special tabulations.

Science & Engineering Indicators – 2002

strong upward trend points to the confluence of two developments: a growing eagerness of universities to exploit the economic potential of research activities conducted under their auspices, and the readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A survey by the Association of University Technology Managers has tracked several indicators of academic patenting, licensing, and related practices. Text table 5-25 summarizes this information for the 1990s. The number of license disclosures, applications, new patents, startup firms, and revenue-generating licenses and options have all grown rapidly.

University income from patenting and licenses reached $641 million in 1999, still low relative to academic research expenditures but more than double the 1995 total. About half of total royalties were classified related to the life sciences; about one-third were not classified; and the remainder, labeled "physical sciences," appears to include engineering.

New licenses and options granted have risen by half since 1995. More than half were granted to startups or other small companies, but about 40 percent went to large firms. Of particular interest is the rise in new equity licenses and options executed relative to the number of startup companies formed, indicating that universities are increasingly taking a longer view of their investments.

Text table 5-25.
Academic patenting and licensing activities: 1991–99

Indicators of activity	1991	1992	1993	1994	1995	1996	1997	1998	1999
	Millions of dollars								
Gross royalties	130.0	172.4	242.3	265.9	299.1	365.2	482.8	613.6	675.5
Royalties paid to others	NA	NA	19.5	20.8	25.6	28.6	36.2	36.7	34.5
Unreimbursed legal fees expended	19.3	22.2	27.8	27.7	34.4	46.5	55.5	59.6	58.0
New research funding from licenses	NA	NA	NA	106.3	112.5	155.7	136.2	126.9	149.0
	Number								
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051	9,555	10,052
New patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644	4,140	4,871
Total patents received	NA	NA	1,307	1,596	1,550	1,776	2,239	2,681	3,079
Startup companies formed	NA	NA	NA	175	169	184	258	279	275
Number of revenue generating licenses, options	2,210	2,809	3,413	3,560	4,272	4,958	5,659	6,006	6,663
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707	3,078	3,295
Equity licenses and options	NA	NA	NA	NA	99	113	203	210	181
	Percent of national academic total represented by responding institutions								
Sponsored research funds	65	68	75	76	78	81	82	83	82
Federal research funds	79	82	85	85	85	89	90	90	90
Patents awarded	NA	NA	81	90	83	82	92	86	92
	Number of reporting institutions								
Number of institutions	98	98	117	120	127	131	132	132	132

NA = not available

NOTE: New research funding refers to research funding to an institution that was directly related to a license or option agreement.

SOURCE: Association of University Technology Managers. AUTM Licensing Survey, various years (Norwalk, CT).

Science & Engineering Indicators – 2002

The Bayh-Dole Act may have contributed to the strong rise in academic patenting in the 1980s, although this activity was already increasing before then. However, the act did stimulate the creation of university technology transfer and patenting units and increased attention to commercially relevant technologies and closer ties between research and technological development. A landmark 1980 Supreme Court ruling (*Diamond* v. *Chakrabarty*) allowing patentability of genetically modified life forms may have been a major stimulus behind the recent rapid increases.

University patenting and collaboration with industry in the United States have contributed to the rapid transformation of new and often basic knowledge into industrial innovations, including new products, processes, and services. Other nations, seeing these benefits, are endeavoring to import these and related practices in an effort to strengthen their innovation systems. In the United States, however, the relative success of university-industry collaboration and academic patenting has raised a number of questions about unintended consequences for universities, academic researchers, and academic basic research.

Concerns have been expressed about potential distortions of the nature and direction of academic basic research and about contract clauses specifying delays or limitations in the publication of research results. The possibility exists that research results may be suppressed for commercial gain, deleterious not only to the conduct of research but potentially also to the perception of academia as an impartial seeker of knowledge. Unsettled questions also arise from faculty members' potentially conflicting economic and professional incentives in their relationships with industry or as officers or equity holders in spinoff firms.

The latter issue also arises for universities, which are moving in the direction of acquiring equity in spinoff firms they generate. They also face the question of balancing their support across different fields or concentrating on a few lucrative areas. Scholars are now asking whether academic patenting practices may in fact be undermining the intended goal of enhancing the transfer of new technologies (National Academies STEP 2001).

Conclusion

Strengths and challenges characterize the position of academic R&D in the United States at the beginning of the 21st century. Its graduate education, linked intimately to the conduct of research, is regarded as a model by other countries and attracts large numbers of foreign students, many of whom stay after graduation. Funding of academic R&D continues to expand rapidly, and universities perform nearly half the basic research nationwide. U.S. academic scientists and engineers are collaborating extensively with colleagues in other sectors and increasingly with international colleagues: in 1999, one U.S. journal article in five had at least one international coauthor. Academic patenting and licensing continue to increase, and academic and other scientific and technical articles are increasingly cited on patents, attesting to the usefulness of academic research in producing economic benefits. Academic licensing and option revenues are growing, as are spinoff companies, and universities are increasingly moving into equity positions to maximize their economic returns.

However, there are challenges to be faced and trends that bear watching. The Federal Government's role in funding academic R&D is declining, and fewer institutions receive these funds. Research-performing universities have increased their own funds, which now account for one-fifth of the total. Industry support has grown, but less than might be surmised given the close relationship between R&D and industrial innovation. Industry support barely reached 8 percent of the total in 1999, well below half of universities' own funds. Spending on research equipment as a share of total R&D expenditures declined to 5 percent during the 1990s, a trend worthy of attention.

Academic employment has undergone a long-term shift toward greater use of nonfaculty appointments, both as postdoctorates and in other positions. A researcher pool has grown independent of growth in the faculty ranks. These developments accelerated during the latter half of the 1990s, when both retirements and new hires were beginning to rise. This raises the question of the future development of these related trends during the next decade, when retirements will further accelerate. Another aspect of this issue is the level of foreign participation in the academic enterprise. Academia has been able to attract many talented foreign-born scientists and engineers, and the nation has benefited from their contributions. However, as the percentage of foreign-born degree-holders approaches half the total in some fields, attention shifts to degree-holders who are U.S. citizens. Among those, majority males have been earning a declining number of S&E doctorates, and they also have shown a disinclination to enter academic careers. On the other hand, the number of S&E doctorates earned by U.S. women and members of minority groups has been increasing, and these new Ph.D.-holders have been entering academia. This development will perhaps aid the growing numbers of students from minority backgrounds expected to enroll in college over the next quarter century by providing role models.

Questions arise about the changing nature of academic research and the uses of its results. The number of U.S. articles published in the world's leading journals is declining in absolute numbers, a trend that remains unexplained. This development follows increased funding for academic R&D and coincides with reports from academic researchers that fail to show any large shift in the nature of their research. Regarding protection of intellectual property, universities moving into equity positions raise conflict-of-interest concerns for institutions and researchers that remain unresolved. Public confidence in academia could decline should academia's research or patenting and licensing activities be perceived as violating the public interest.

Selected Bibliography

Association of University Technology Managers, Inc. (AUTM). 2000. *AUTM Licensing Survey, Fiscal Year 1991–1999*. Norwalk, CT.

Blackburn, R., and J. Lawrence. 1986. “Aging and the Quality of Faculty Job Performance,” *Review of Educational Research* (Fall): 265–290.

Blumenthal, D., E.G. Campbell, M.S. Anderson, N. Causino, and K. Seashore Louis. 1997. “Withholding Research Results in Academic Life Science.” *The Journal of the American Medical Association* (April 16). Available at <http:// www. ama-assn.org/sci-pubs/journals/archive/jama/ vol_277/no_15/oc6d11.htm>. Accessed May 2001.

Brainard, J., and R. Southwick. 2000. “Congress Gives Colleges a Billion-Dollar Bonanza in Earmarked Projects.” *The Chronicle of Higher Education* 46 (July 28): A29.

———.2001. “A Record Year at the Federal Trough: Colleges Feast on $1.67 in Earmarks.” *The Chronicle of Higher Education* 47 (August 10): A20.

Carnegie Foundation for the Advancement of Teaching. 1994. *A Classification of Institutions of Higher Education*. Princeton.

Central Intelligence Agency (CIA). 1998. *CIA World Factbook 1998.* Langley, VA.

European Commission. 1997. *Second European Report on S&T Indicators.* Brussels.

Florida, R. 1999. “The Role of the University: Leveraging Talent, Not Technology.” *Issues in Science and Technology* (Summer). Available at <http://www.http:// www.nap.edu/issues/15.4/florida.htm>. Accessed May 2001.

Geisler, E. 2001. “The Mires of Research Evaluation,” *The Scientist* 15(10): 39. Available at <http://www.the-scientist.com/yr2001/may/opin_010514.html >. Accessed May 2001.

Goldman, C.A., and T. Williams, with D.M. Adamson and K. Rosenblatt. 2000. *Paying for University Research Facilities and Administration*. Santa Monica, CA: Science and Technology Policy Institute, RAND.

Gotbaum, J. 2001. “Clarification of OMB A-21 Treatment of Voluntary Uncommitted Cost Sharing and Tuition Remission Costs.” Memorandum M-01-06. Washington DC: Office of Management and Budget, Executive Office of the President.

Huttner, S. 1999. “Knowledge and the Biotech Economy: A Case of Mistaken Identity.” Paper presented at the High Level CERI/OECD/NSF Forum on Measuring Knowledge in Learning Economies and Societies, Arlington, VA. May.

International Bank for Reconstruction and Development (World Bank). 2000. *World Development Indicators, 2000.* Washington, DC.

Levin, S., and P. Stephan. 1991. “Research Productivity Over the Life Cycle: Evidence for Academic Scientists.” *American Economic Review* 81 (March): 114–32.

National Academies Board on Science, Technology and Economic Policy (National Academies STEP). 2001. Intellectual Property in the Knowledge-Based Economy. www4. nationalacademies.org/pd/step.nsf

———. Forthcoming. *Trends in Federal Support of Research and Graduate Education*. Washington, DC.

National Research Council (NRC). 1991. *Ending Mandatory Retirement for Tenured Faculty.* Washington, DC: National Academy Press

National Science Board. 2000. *Science and Engineering Indicators 2000*. NSB-00-1. Arlington, VA: National Science Foundation.

National Science Board. 1996. *Science & Engineering Indicators 1996.* NSB-96-21. Arlington, VA.

National Science Foundation (NSF), Division of Science Resources Statistics. 1995a. *Guide to NSF Science/Engineering Resources Data.* NSF 95-318. Arlington, VA.

———. 1995b. *NSF Survey Instruments Used in Collecting Science and Engineering Resources Data.* NSF 95-317. Arlington, VA.

———. 1996. *Human Resources for Science and Technology: The European Region.* NSF 96-316. Arlington, VA.

———. 1998. *How Has the Field Mix of Academic R&D Changed?* NSF 99-309. Arlington, VA.

———. 2000a. *Latin America: R&D Spending Jumps in Brazil, Mexico, and Costa Rica.* NSF 00-316. Arlington, VA.

———. 2000b. *National Patterns of R&D Resources: 2000 Data Update*. NSF 01-309. Arlington, VA.

———. 2001a. *Academic Science and Engineering R&D Expenditures: Fiscal Year 1999.* Detailed Statistical Tables. NSF 01-329. Arlington, VA.

———. 2001b. *Federal Funds for Research and Development: Fiscal Years 1999, 2000, and 2001.* Detailed Statistical Tables. Vol. 49. NSF 01-328. Arlington, VA.

———. 2001c. *Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions.* Fiscal Year 1999. Detailed Statistical Tables. NSF 01-323. Arlington, VA.

———. 2001d. *Scientific and Engineering Research Facilities at Universities and Colleges: 1998.* NSF 01-301. Arlington, VA.

———. 2001e. *Scientific and Engineering Research Facilities: 1999*. NSF 01-330. Arlington, VA.

———. Forthcoming. *Characteristics of Doctoral Scientists and Engineers in the United States: 1999.* Detailed Statistical Tables. Arlington, VA.

New York Times. 2001. “Technology Intensifies the Law of Change.” Interview with Gordon E. Moore. (May 27).

Organization of American States. 1997. “Science & Technology Indicators.” *Iberoamerican/Interamerican*. Washington, DC.

Raghuram, N., and Y. Madhavi. 1996. “India’s Declining Ranking” *Nature* 383 (October 17): 572.

U.S. House of Representatives, Committee on Science, Space, and Technology. 1993. "Academic Earmarks: An Interim Report by the Chairman of the Committee on Science, Space, and Technology." Washington, DC.

U.S. Office of Management and Budget (OMB). 2000. *Cost Principles for Educational Institutions.* Circular A-21. Washington, DC: U.S. Government Printing Office.

———. 2001. "Analytical Perspectives." *Budget of the United States Government, Fiscal Year 2002*. Washington, DC: U.S. Government Printing Office.

U.S. Office of Science and Technology Policy (OSTP). 2000. *Analysis of Facilities and Administrative Costs at Universities.* Washington DC.

U.S. Patent and Trademark Office (PTO). 2000. *Technology Assessment and Forecast Report, U.S. Universities and Colleges, 1969–99.* Washington, DC.